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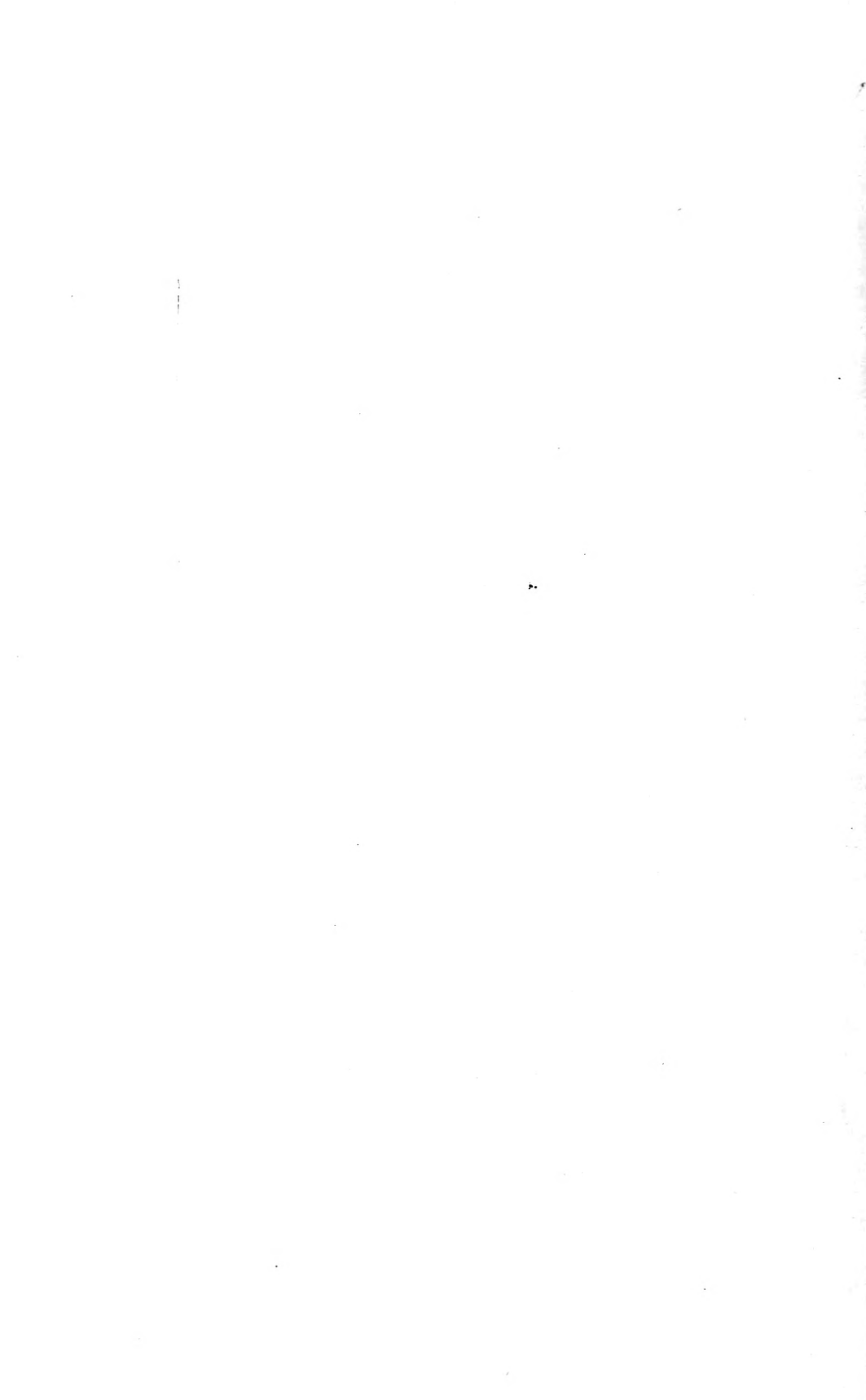
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Mineral

A K E Y

FOR THE DETERMINATION OF

# Rock-Forming Minerals in Thin Sections

BY

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*Member U. S. Geological Survey*

*FIRST EDITION*

FIRST THOUSAND

NEW YORK

JOHN WILEY & SONS

London: CHAPMAN & HALL, Limited

1908

104149  
11/1/10

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The Scientific Press  
Robert Drummond and Company  
New York

## PREFACE.

THE determination of rocks is largely based upon the identification of their component minerals, and since it is only in coarse, granular rocks that these can be identified megascopically, it is commonly necessary to employ microscopical methods. A knowledge of the usual appearance of the minerals as they occur in rock sections is not sufficient, because many of them are very similar, and one must be familiar with the application of the optical methods by which they are determined to secure accurate results.

Tables for the determination of minerals have heretofore been made of secondary importance in text books. In this volume the reverse method has been adopted and the descriptive tables make up the greater portion of the book. Theoretical discussions in optics have been avoided so far as possible, and only enough has been given to make clear that which is necessary for the practical determination of the minerals. The material has been condensed as much as is consistent with clearness, and all of the descriptions are given in as concise a form as possible.

Owing to the difficulty of having the pages of the index indented by machinery, it was found necessary to extend the leaves to the full width of the book, and to indicate the lines along which the student should cut the pages. After trimming along the lines shown, it will be found convenient to form another index guide by cutting off about one-half inch from the upper right hand corners of the pages descriptive of negative minerals.

In the preparation of this book I have constantly referred to the fourth edition of Professors Rosenbusch and Wülfing's "*Mikroskopische Physiographie der petrographisch wichtigen Mineralien*," and to them my thanks are due for their kindness in granting me permission to reproduce certain diagrams and figures from their book. Among these are a number of the feldspar diagrams which I have redrawn and, in some cases, slightly modified. For convenience in showing the relation between the percentage proportions of the albite-anorthite molecules and the common names, I have inserted above each diagram these names, limiting them as the best usage seems to warrant. For the mineral descriptions in Part III, I have consulted the works of Rosenbusch, Lévy and Lacroix, Dana, Groth, and Hintze. Many of the methods in the chapter on the feldspars are from A. Michel-Lévy's "*Etude sur la détermination des feldspaths*" and I am greatly indebted to him for permitting me to reproduce his diagrams and the valuable color plate published in Lévy and Lacroix's "*Minéraux des Roches*."

The student who wishes more complete theoretical discussions of the principles underlying the optical methods, is referred to the works mentioned above and also to Professor Iddings' "*Rock Minerals*," which has appeared since the manuscript of this book was completed.

From the nature of the tables it is very probable that some errors have escaped my notice. I shall be glad to be notified of any such that may be found.

ALBERT JOHANNSEN.

U. S. GEOLOGICAL SURVEY, WASHINGTON, D.C.,  
November 26, 1907.



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# PART I.

## INTRODUCTION.

Ornari res ipsa negat,  
Contenta docere.

MANILIUS, *Astronomica*, 3, 39.





## INTRODUCTION.

### ERRATA.

- Page 3, line 7. Color of, should be color upon.  
Page 16, Anise oil, index of refraction should be 1.56.  
Page 36, line 4. The first and third. should be two of the.  
Page 37, line 4. Second and fourth, should be N.E. and S.W.  
Page 37, line 5. First and third, should be N.W. and S.E.  
Page 63, line 31. Ce; above  $90^\circ$  of Ce the, should be Ce from  $60^\circ$  to  $90^\circ$ ; above  $2V = 90^\circ$  the.  
Page 75. Anorthoclase, at top of page, should be Anorthite.  
Page 124. Foselite, should be Noselite.  
Page 228. Diaspore should be optically positive.  
Page 294. Diaspore should be optically positive.  
Page 393, line 15. Reactions and weak, K should be reactions, and weak K.  
Page 449, line 17. Onit comma.

of isotropic substances, therefore, are dark between crossed nicols, and remain so during the rotation of the stage.

Isotropic substances are of two classes: amorphous bodies and fluids, and crystals of the isometric system.

Amorphous substances have no crystalline character and



## INTRODUCTION.

### **Light.**

IN a homogeneous medium, light is transmitted in straight lines without change of direction and by means of vibrations at right angles to the direction of movement.

The **intensity** of the light depends upon the amplitude of this movement, and the color of the rate. Extreme red light has about 443,000,000,000,000 waves in a second, while extreme violet has about 702,000,000,000,000.

When light is made to vibrate in a single plane, as by passing through a nicol prism, it is said to be **polarized**. Since the direction of vibration in the nicol prism of the analyzer is at right angles to that in the polarizer, the light is completely cut off in passing through the two.

### **Isotropic Media.**

Substances in which the velocity of the transmission of light is independent of the direction of vibration are called **isotropic**. In such a body the form of the wave-surface may be represented by a sphere. Under the microscope the light from the polarizer is unchanged in passing through the mineral section, consequently it is completely cut off by the analyzer and no interference phenomena are produced. All sections of isotropic substances, therefore, are dark between crossed nicols, and remain so during the rotation of the stage.

Isotropic substances are of two classes: amorphous bodies and fluids, and crystals of the isometric system.

Amorphous substances have no crystalline character and

allow the light to vibrate with the same ease in all directions.

Isometric crystals have crystalline form, but the ease of vibration is the same in all directions.

### **Anisotropic Media.**

In anisotropic media the velocity of the transmission of light varies with the direction. Anisotropic crystals are uniaxial or biaxial. In a uniaxial crystal the surface of wave velocities is an ellipsoid of rotation; in a biaxial crystal it approaches the form of an ellipsoid of three axes.

All substances that are not amorphous or of the isometric system are optically anisotropic. They may be divided into two groups:

1. **Uniaxial crystals**, or those which have but one optic axis; that is, but one direction along which there is no double refraction. The optic axis coincides with the crystallographic axis  $c$ , which is also the direction of either the greatest or least ease of vibration. Tetragonal and hexagonal crystals belong here.

2. **Biaxial crystals**, or those with two optic axes. To these belong orthorhombic, monoclinic, and triclinic crystals.

In the orthorhombic system the axes of maximum and minimum ease of vibration coincide with the crystallographic axes; in the monoclinic and triclinic systems they do not.

### **Index of Refraction.**

A ray of light passing from one medium to another undergoes various changes; a part of the light does not enter the second medium but is reflected back, and a part is transmitted through the second medium but has its direction changed, that is, it is refracted.

Beyond a certain angle, characteristic for each mineral, light is totally reflected and none is refracted. The angle of incidence at which this takes place is called the **critical angle**.

The ratio of the sine of the angle of incidence to the sine of the angle of refraction is constant for the same media and is called the **index of refraction**. It is inversely proportional to the wave velocity. In isotropic media this index is the same in every direction, while in anisotropic media it varies in different directions.

### **Double Refraction.**

A ray of light entering an anisotropic medium is resolved into two rays vibrating at right angles to each other with different velocities, although the difference in rate is very slight. When the ray is vibrating parallel to the direction of greatest ease of vibration, it advances fastest; and slowest when parallel to the direction of least ease. In consequence of the two different light velocities, there must be, also, two different indices of refraction. As the stage of the microscope is rotated, the axes of light vibrations will coincide with the planes of vibration of the nicols four times, at intervals of  $90^\circ$ , and will produce darkness each time.

This property of anisotropic crystals of resolving the light vibrations into two sets at right angles to each other, is called **double refraction**. Since in anisotropic minerals the rate of vibration is different in different directions, it follows that this difference is still found in the components of these rays after they have passed through the analyzer, consequently one of the waves reaches the eye slightly in advance of the other, although in the same plane after passing the analyzer. The interference of the two produces an **interference color**.

The directions of greatest and least ease of vibration, which are always at right angles to each other, and a third direction at right angles to these two, form the **axes of elasticity** or **vibration axes**. They are indicated by the German letters **a**, **b**, and **c**: **a** is considered the direction of greatest ease of vibration, also called the direction of maximum elasticity; **b** is the direction of intermediate ease of vibration or elasticity; and **c** is the direction of least ease of vibration. All of these

velocities vary inversely as the indices of refraction. The planes of which these lines are the intersections are called the **principal optic sections**. They always contains two axes of elasticity.

### **Monochromatic Light.**

In many observations, as for dispersion, etc. (see p. 32), monochromatic light is used. This may be produced by the absorption of certain rays by means of glasses or ray-filters, by monochromatic flames produced by vaporizing certain substances, or by means of a monochromator, which breaks white light into the spectrum. For use under the microscope all but the first are too complicated.

### **Optically Uniaxial Crystals.**

Of the two rays of light resulting from the double refraction of a ray passing through a uniaxial crystal, one vibrates with equal velocity in every direction. This is called the **ordinary ray** and its wave-surface is a sphere. Its index of refraction is denoted by  $\omega$ . The second ray is called the **extraordinary ray** and its index of refraction is denoted by  $\epsilon$ . It passes through the crystal with different velocities in different directions, agreeing only in one direction with the ordinary ray. In this direction, consequently, there will be no double refraction, since the values of  $\omega$  and  $\epsilon$  are equal; in other words, this is an **axis of isotropy**. In the tetragonal and hexagonal systems this direction of greatest or least ease of vibration coincides with crystallographic  $c$ , which is also an optic axis. All waves moving at the same angle with this axis have equal velocities, consequently any section of the wave-surface figure at right angles to this axis is a circle, while every other section of the wave-surface is an ellipse.

**Positive and negative uniaxial crystals.** From the above it is seen that there are two kinds of uniaxial crystals. In one the extraordinary ray has its greatest velocity along the principal axis; in the other this is the direction of least velocity.

These relationships are shown in Figs. 1 and 2, which are sections through the centers of the wave-velocity figures. In Fig. 1  $\varepsilon > \omega$ , and in Fig. 2,  $\varepsilon < \omega$ . The velocities shown are, as noted above, inversely proportional to the indices.

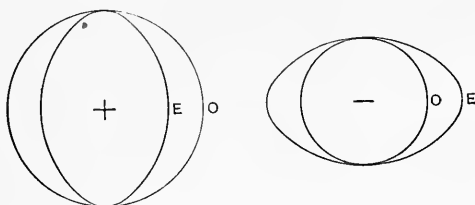


FIG. 1.

FIG. 2.

FIGS. 1 and 2.—Wave-surfaces of positive and negative uniaxial crystals. O=Ordinary ray. E=Extraordinary ray.

**Optically positive (+) crystals.** A uniaxial crystal is considered positive when crystallographic  $c$  is the direction of the least ease of vibration ( $c = r$ ) and the index of refraction of the extraordinary ray is greater than that of the ordinary ray ( $\varepsilon > \omega$ ).

**Optically negative (−) crystals.** A uniaxial crystal is considered negative when crystallographic  $c$  is the direction of greatest ease of vibration ( $c = n$ ) and ( $\varepsilon < \omega$ ).

**Principal optic section.** A principal optic section is one containing the axes of greatest and least ease of vibration. In uniaxial crystals any section parallel to crystallographic axis  $c$  is a principal section.

**Measure of the double refraction.** The value of the double refraction is expressed by the difference between the indices. In a uniaxial crystal the difference between the values of  $\omega$  and  $\varepsilon$  is greatest in sections parallel to the optic axis, and therefore this section shows the highest interference colors.

### Optically Biaxial Crystals.

Besides crystals with an axis of isotropy, there are others with no axis of isotropy but with two optic axes. In these crystals the wave-surface approaches the form of a three-axis ellipsoid.

The index of refraction of the rays with vibrations parallel to **a** and advancing at right angles to **a**, in biaxial crystals, is represented by  $\alpha$ .

The index of refraction of rays with vibrations parallel to **b** and advancing at right angles to **b**, in biaxial crystals, is represented by  $\beta$ .

The index of refraction of rays with vibrations parallel to **c** and advancing at right angles to **c**, in biaxial crystals, is represented by  $\gamma$ .

The positions of the axes of elasticity vary in different crystals. In orthorhombic crystals the axes of elasticity coincide with the crystallographic axes.

In monoclinic crystals one axis of elasticity coincides with crystallographic axis *b*; the other two axes of elasticity are inclined to crystallographic axes *a* and *c*, but are in the same plane.

In triclinic crystals no axis of elasticity coincides with, or is parallel to, a crystallographic axis.

**Interference colors.** In biaxial crystals the interference colors differ with the orientation of the section. They are highest in sections parallel to the plane of the optic axes, that is, in sections parallel to the plane of **a** and **c**. The value is  $\gamma - \alpha$ .

**Optic axes** are directions in a crystal in which the rays of light traverse it without being doubly refracted. (*A* and *C*,

Fig. 3.)

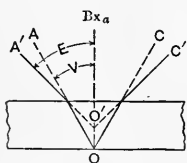


FIG. 3.—True and apparent axial angles.

**Axial angle.** The axial angle is the angle between the optic axes. The true value is expressed by  $2V$ , the apparent value in air by  $2E$ , and the value obtained by immersion in water, oil, etc., by  $2H$ . (Fig. 3.) When the value of the axial angle is less than  $90^\circ$ , it is called the **acute axial angle**; the other angle between the optic axes is the **obtuse axial angle**.

**Bisectrix.** The line bisecting the axial angle is called the



bisectrix. When it occurs in the acute axial angle, it is called the **acute bisectrix**; when in the obtuse axial angle, it is called the **obtuse bisectrix**. The bisectrices are the directions of maximum ( $\alpha$ ) and minimum ( $\epsilon$ ) ease of vibration. ( $Bx_a$  in Fig. 3.)

**Plane of the optic axes.** The plane containing the two optic axes is called the plane of the optic axes. It necessarily also contains the directions of greatest and least ease of vibration.

**Optic normal.** The line at right angles to the plane of the optic axes, that is, the line at right angles to the plane of  $\alpha$  and  $\epsilon$ , is called the optic normal. It is the direction of  $\delta$ .

**Optic binormals** are the two optic axes.

**Optically positive (+) biaxial crystals.** The mineral is considered optically positive when  $\epsilon$  is the acute bisectrix.

**Optically negative (-) biaxial crystals.** The mineral is considered optically negative when  $\alpha$  is the acute bisectrix.

**Newton's color scale.** Increasing the thickness of a section produces a rise in the interference tints until finally white of the higher orders appears. The thickness at which this is produced is different in different minerals. It is less in those having a large value for  $\gamma - \alpha$ .

The following table is modified from Quineke.\*

Certain colors occur periodically in the table and are called orders. The violet, showing a wave difference of .000575 mm., is the most sensitive tint in the whole scale; a very slight increase or decrease in the wave length produces a marked change in the color. Decreasing the wave length by .000024 mm. changes it to a deep red, and increasing it .000014 mm. to indigo.

A list of the values of the maximum birefringences ( $\gamma - \alpha$ ) of the different minerals is given in Part IV.

---

\*G. Quineke: Poggendorff's *Annalen der Physik und Chemie*, 1866, p. 177.

NEWTON'S COLOR SCALE.  
(Modified from Quinceke.)

No.	Difference in Wave Length.	Phase Difference for Na Light.	Interference Colors Between Crossed Nicols.	Interference Colors Between Parallel Nicols.
1	0.000000 mm.	0	Black. . . . .	Bright white
2	40	...	Iron gray. . . . .	White
3	97	...	Lavender gray. . . . .	Yellowish white
4	158	$\frac{1}{4}$	Grayish blue. . . . .	Brownish white
5	218	...	Clearer gray. . . . .	Brownish yellow
6	234	...	Greenish white. . . . .	Brown
7	259	...	Almost pure white. . .	Light red
8	267	...	Yellowish white. . . .	Carmine
9	275	...	Pale straw yellow. . .	Dark reddish brown
10	281	...	Straw yellow. . . . .	Deep violet
11	306	$\frac{1}{2}$	Light yellow. . . . .	Indigo
12	332	...	Bright yellow. . . . .	Blue
13	430	...	Brownish yellow. . . .	Grayish blue
14	505	$\frac{3}{4}$	Reddish orange. . . .	Bluish green
15	536	...	Red. . . . .	Pale green
16	551	...	Deep red. . . . .	Yellowish green
17	565	...	Purple. . . . .	Lighter green
18	575	...	<b>Violet.</b> . . . .	Greenish yellow
19	589	1	Indigo. . . . .	Golden yellow
20	664	...	Sky blue. . . . .	Orange
21	728	...	Greenish blue. . . . .	Brownish orange
22	747	...	Green. . . . .	Light carmine
23	826	...	Lighter green. . . . .	Purplish red
24	843	...	Yellowish green. . . .	Violet purple
25	866	...	Greenish yellow. . . .	Violet
26	910	$\frac{3}{2}$	Pure yellow. . . . .	Indigo
27	948	...	Orange. . . . .	Dark blue
28	998	...	Bright orange red. . .	Greenish blue
29	1101	...	Dark violet red. . . .	Green
30	1128	...	Light bluish violet. . .	Yellowish green
31	1151	2	Indigo. . . . .	Impure yellow
32	1258	...	Greenish blue. . . . .	Flesh colored
33	1334	...	Sea green. . . . .	Brownish red
34	1376	...	Brilliant green. . . .	Violet
35	1426	$\frac{5}{2}$	Greenish yellow. . . .	Grayish blue
36	1495	...	Flesh color. . . . .	Sea green
37	1534	...	Carmine. . . . .	Green
38	1621	...	Dull purple. . . . .	Dull sea green
39	1652	...	Violet gray. . . . .	Yellowish green
40	1682	...	Grayish blue. . . . .	Greenish yellow
41	1711	...	Dull sea green. . . .	Yellowish gray
42	1744	3	Bluish green. . . . .	Lilac
43	1811	...	Light green. . . . .	Carmine
44	1927	...	Light greenish gray. .	Grayish red
45	2007	...	Whitish gray. . . . .	Bluish gray
46	2048	...	Flesh red. . . . .	Green

Compare color plate in Part IV.

### ***Examination in Parallel Polarized Light.***

Parallel polarized light is used to determine whether a mineral is singly or doubly refracting. In doubly refracting minerals it is used to observe the positions of the axes of vibration in relation to the crystallographic axes, the index of refraction, and the birefringence.

#### **Isotropic Plates in Parallel Polarized Light.**

If one inserts a flake of an isotropic mineral between the polarizer and analyzer of a microscope, there will be no alteration in the directions of vibration of the rays of light on account of the equal ease of vibration in every direction, consequently the field will remain dark for both colored and colorless minerals. This property of remaining dark between crossed nicols, in any position in its own plane or any other plane, is the most important characteristic of an isotropic mineral.

#### **Anisotropic Plates in Parallel Polarized Light.**

A plate of a transparent doubly refracting mineral which is not cut at right angles to an optic axis, when inserted between crossed nicols in white light, shows chromatic interference.

The intensity of the light (not intensity of color) depends upon the value of  $\sin^2 2\phi$ ; in which  $\phi$  is the angle which the optic principal section of the slide makes with the principal section of the polarizer or analyzer. When the optic principal section coincides with ( $\phi = 0^\circ$ ) or is at  $90^\circ$  to that of the polarizer or analyzer, this value is equal to zero; consequently there will be extinction four times upon rotating the stage of the microscope. When  $\sin^2 2\phi = 1$  the principal section is at  $45^\circ$  to the principal section of the polarizer or analyzer and the light intensity is at a maximum.

**Anisotropic plates at right angles to an optic axis in parallel polarized light.** In tetragonal and hexagonal crystals the principal crystallographic axis coincides with the optic

axis, therefore the optic axis is a direction of single refraction, and a basal plane between crossed nicols acts, in parallel light, as an isotropic body.

**Superimposed anisotropic plates in parallel polarized light.**

If two plates lie at right angles or parallel to each other, they act as a single plate with reference to the extinctions at  $90^\circ$ . When the directions of greatest and least ease of vibration correspond, the wave differences of the two are added, and the interference colors rise; when unlike ease of vibrations are parallel, the color sinks to the difference between the two wave lengths. If the wave differences are alike, the sum is equal to zero and darkness results, and the field of the microscope remains dark on rotating the stage.

**Extinction.**

Both uniaxial and biaxial crystals appear dark between crossed nicols when their principal sections coincide with the vibration planes of the nicols. For most determinations white light answers the purpose, and only for minerals having strong dispersion of the bisectrices is it necessary to use the more accurate monochromatic light. (See p. 6.)

**Determination of extinction angles.** (a) *To observe the extinction angle* the vibration directions of the analyzer and polarizer of the microscope must be at right angles. The stage, with the mineral section upon it, is turned until the point of darkness is reached. This operation should be repeated ten times, and then again ten times with the stage rotated  $180^\circ$  from the position in which the first observations were made. An average of the twenty readings will give the extinction angle.

(b) *With gypsum plate.* Since the eye is somewhat insensible to small variations in the intensity of light, there may be considerable variation in reading the position of extinction. To overcome this one may use a gypsum plate producing red of the first order. If the mineral section whose extinction is

to be determined is placed between crossed nicols, so that it covers only a part of the field of the microscope, and the gypsum plate is inserted in the slot of the microscope above it, the mineral will appear of a different color from the remainder of the field, since its vibrations are added to or subtracted from that of the gypsum. If the stage is now rotated until the entire field is uniformly colored, the axes of greatest and least ease of vibration of the mineral will coincide with the directions of the cross-hairs of the microscope, and the amount of rotation can be read from the graduated circle upon the stage.

(c) *Klein quartz plate.* The gypsum plate is only of use in the determination of the extinction of colorless minerals; for those that are highly colored a Klein quartz plate is used. This consists of a quartz plate 3.75 mm. in thickness and cut at right angles to the axis. In consequence of the circular polarization of the quartz, one may obtain different interference colors by turning the analyzer; among others red of the first order appears when the nicols are nearly parallel. For determining the extinction of colored minerals, that tint is chosen which is most sensitive to the extinction of that mineral. The method of determining the angle is the same as with the gypsum plate, except that in general the nicols are not crossed.

(d) *Bertrand ocular.* The most exact method for the determination of extinction is by means of a Bertrand ocular. This consists of an ocular containing two right and two left-handed quartz plates of the same thickness, cut perpendicular to the axis, and so inserted that the lines of contact between the four parts are exactly parallel to the principal sections of the nicol prisms (Fig. 4). When the lower and cap nicols are crossed and a doubly refracting plate is inserted between them, the adjacent quadrants become differently colored, while the diagonal ones are alike. Upon rotating the stage the four quadrants become uniformly colored when the principal sections of the mineral are parallel to those of the nicols. The

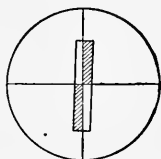


Fig. 4.—Bertrand ocular.

amount of rotation of the stage is the measure of the extinction.

**Orientation.** In tetragonal, hexagonal, and orthorhombic crystals the position of extinction is always parallel or symmetrical to the cleavage cracks.

In monoclinic crystals the extinction is parallel or symmetrical to the cleavage only in the zone parallel to the *b* axis. In all other sections the extinction is oblique.

In triclinic crystals the extinction directions are, in general, inclined to the cleavage lines.

### Determination of the Relative Indices of Refraction of Minerals.

(a) *Becke's method*\* for the determination of the relative indices of refraction of minerals in contact with each other is to focus sharply upon the line of contact between them with a medium power objective in parallel light. The plane of contact between the two minerals should be nearly at right angles to the plane of the thin section and free from inclusions of dust, etc. The rays, passing from a denser to a rarer medium at less than the critical angle, will be reflected back into the denser medium, thus increasing the light emerging from it, while on the side of the rarer medium it will be decreased. In consequence there is a narrow bright band along the contact on the side of the denser medium. By raising the objective slightly this band passes in the direction of the denser medium. This is much more noticeable if the lower diaphragm of the microscope is partially closed. Knowing one of the minerals, the relative index of the other in contact is thus determined. This method is very delicate and a difference of refraction of 0.001 can be observed.

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\* F. Becke: Sitzungsberichte der K. K. Akademie der Wissenschaften zu Wien, vol. 102, 1893, pp. 358-376; Tschermak's Mineralogische und petrographische Mitteilungen, v. 13, 1892-3, pp. 385-388.

Thus the indices of

anorthite,  $n = 1.580$ ,

labradorite,  $n = 1.559$ ,

andesine,  $n = 1.553$ ,

are all greater than

quartz,  $n = 1.551$ ;

which is greater than

nephelite,  $n = 1.545$ ,

oligoclase,  $n = 1.543$ ,

which is greater than

Canada balsam,  $n = 1.54 +$ ;

which is greater than

albite,  $n = 1.531$ ,

orthoclase,  $n = 1.523$ .

The use of this method in the determination of the feldspars is more fully explained in Part II, pp. 72-76.

(b) *Method of embedding of Schroeder van der Kolk*.\* If a substance is immersed in a fluid of exactly the same index of refraction, dispersion, and color, its boundaries will completely disappear and it will become invisible.

In applying this method to the determination of the index of refraction of a mineral, a fragment is immersed in a fluid having a certain index of refraction. Upon raising the tube of the microscope slightly (see preceding section), the bright line will move into the center of the mineral if this is of a higher index, and into the fluid if the reverse is true. By successive trials with liquids of different refractive indices, or by increasing or reducing the index of the fluid by the addition of another fluid of higher or lower index, the index of refraction of the mineral may be quickly found. Owing to the fact that the

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\* Tabellen zur mikroskopischen Bestimmung der Mineralien nach ihrem Brechungsindex, 1900.

dispersion of the mineral and the liquid are usually not the same, instead of completely losing its boundaries the mineral will show bright-colored bands around its edges. To determine the refractive index of the liquid, Schroeder v. d. Kolk used a total reflectometer. In applying this method to the determination of the feldspars, Michel-Lévy used a series of sixteen minerals with known indices as indicators instead of the reflectometer, and, since some of van der Kolk's solutions acted upon the minerals, he used Klein's solution variously diluted. In Schroeder v. d. Kolk's Tabellen is given a list of 200 minerals arranged according to their indices of refraction, and a series of fluids with different indices of refraction which are of use in these determinations. The following list is taken partly from his table and partly from Maschke's.\*

*Indices of refraction of immersion fluids.*

Solution of mercury iodide in aniline and chinoline	$n=2.2+$
Phosphorus, solid. ....	$n=2.144$
“        molten. ....	2.075 †
Sulphur (molten at 110°).....	1.93
Sulphur in iodo methylene.....	1.83
Bisulphide of carbon. ....	1.768
Iodo methylene . . . . .	1.740
$\alpha$ -Monobrom naphthalene.....	1.658
Anise oil. ....	1.639
$\alpha$ -Monochlor naphthalene.....	1.639
Monoiodo benzene. ....	1.621
Cassia oil at 21°. ....	1.606
Cinnamon oil. ....	1.605
Bromoform. ....	1.588
Monobrom benzene. ....	1.561
Nitro benzene. ....	1.554
Clove oil. ....	1.544

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\* Wiedemann's Annalen der Physik und Chemie, vol. xi, 1880, pp. 722-734.

† Remains fluid for some time under a cover-glass.



Canada balsam.....	1.542-1.55
Ethylene bromide.....	1.536
Monoehlor benzene.....	1.527
Cedar oil.....	1.516
Benzene.....	1.501
Xylene.....	1.495
Beechnut oil.....	1.477
Almond oil at 21°.....	1.469
Carbon tetrachloride.....	1.466
Glycerine (1.23-1.25 sp. gr.) at 15.5°.....	1.460
Amyl alcohol at 15.5° C.....	1.4075
Water at 18° C.....	1.333

Except as marked, the temperature at which these indices were taken was approximately 15° C.

To obtain fluids of different indices, glycerine may be mixed with water, almond oil with amyl alcohol or with cassia oil, or cassia oil with amyl alcohol. It is thus possible to obtain a series of fluids of any desired index of refraction from 1.333 to 1.606.

Maschke used a series of mixtures of cassia oil and almond oil as follows:

Almond Oil.	Cassia Oil.	Index for D.
( 1) 5 parts (by weight)	$\frac{1}{3}$ part	1.474 at 20.8°
( 2) 5 " "	$\frac{1}{2}$ "	1.476 " 20.8°
( 3) 5 " "	1 "	1.485 " 20.3°
( 4) 5 " "	2 "	1.501 " 20.3°
( 5) 5 " "	3 "	1.5105 " 20.6°
( 6) 5 " "	4 "	1.519 " 20.6°
( 7) 5 " "	5 "	1.526 " 20.3°
( 8) 5 " "	6 "	1.533 " 20.3°
( 9) 5 " "	7 "	1.5375 " 20.6°
(10) 5 " "	$7\frac{1}{4}$ "	1.540 " 20.0°
(11) 5 " "	8 "	1.543 " 20.6°
(12) 5 " "	9 "	1.5445 " 20.6°
(13) 5 " "	10 "	1.5466 " 20.6°

(14) 5 parts (by weight)	11 parts	1.551 at 20.8°
(15) 5 " "	12 "	1.552 " 20.8°
(16) 5 " "	13 "	1.555 " 20.8°
(17) 5 " "	14 "	1.560 " 20.8°
(18) 5 " "	15 "	1.5625 " 20.8°
(19) 5 " "	15 "	1.562 " 21.75°

Mixtures of cassia and almond oils should be kept in well stoppered bottles, for the index appreciably decreases by the oxidation of the cassia oil to cinnamic acid.

#### Tables of Mean Indices of Refraction.

See Part IV.

#### Determination of the Order of Birefringence.

The birefringence of a mineral (the difference between the indices,  $\omega$  and  $\varepsilon$ , or  $\gamma$  and  $\alpha$ , etc.), like the index, is characteristic for that mineral. When the indices are known the values of the birefringence in different directions can be computed or they can be approximately determined by comparing the colors seen under the microscope with those on a color scale.

Since the color seen in a mineral between crossed nicols is dependent upon the thickness of the section as well as upon the birefringence of the mineral, one must first compare the color with that of a known mineral to determine the thickness of the slide. Good slides vary but little in different parts of the section, and uneven grinding does not greatly interfere. For comparison of colors and thicknesses, the plate prepared by Michel-Lévy\* is of great service. This is reproduced with some modifications in Part IV. Although it is not possible to reproduce the exact colors of nature, no difficulty will be found in determining the color seen.

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\* Lévy et Lacroix, Les Minéraux des Roches.

The method of using the plate is as follows: The thickness of the section is first determined by observing the highest color shown by some known mineral. The inclined line of its birefringence on the plate is followed to that color, and the thickness is read at the left along the horizontal line. After observing the highest interference color of the unknown mineral, this color is found along the horizontal line giving the thickness of section, and the inclined intersecting line is followed upwards to the right, where the name of the unknown mineral will be found. The plate shows the maximum birefringences of the minerals, and one must observe a number of sections to be certain that the one chosen shows the highest color.

A list of the values of the maximum birefringences of different minerals is given in Part IV.

There are numerous methods and accessories used in determining the order of birefringence. Those of most importance are:

(a) *Quarter undulation mica plate.* When the  $\alpha$  axis of the mica plate and that of the section are at right angles, the color seen between crossed nicols will drop one-quarter order in the scale: thus the first-order yellow will be reduced to white, while the second-order yellow will become green. This method can be used to advantage in distinguishing the lower orders.

(b) *Gypsum plate with red of the first order.* The first-order red can be separated from the higher orders by the use of a gypsum plate giving red of the first order. When the  $\alpha$  axis of this plate and that of the section are at right angles, the color will drop through one order and become dark; a second-order red will be reduced to a first-order red. This method is of value for the middle orders.

(c) *Quartz wedge.* For the higher orders a quartz wedge may be used. The mineral section is turned until the directions of maximum and minimum ease of vibration make angles of  $45^\circ$  with the cross-hairs of the microscope; that is, the section is turned until the mineral is  $45^\circ$  off extinction. The

quartz wedge is inserted with its thin edge forward and its  $a$  direction parallel to the  $c$  direction of the mineral. The interference colors, therefore, descend through the scale of Newton's colors, as the wedge is pushed forward, until the acceleration of the one exactly coincides with the retardation of the other, and, the vibrations neutralizing each other, the section appears dark. The mineral section is removed and the number of times ( $n$ ) is counted, that the original color recurs on withdrawing the wedge. The original color must then have been of the  $n+1$  order.

(d) *Mica compensator of E. von Fedorow.\** In using this wedge the process is essentially the same as with the quartz wedge, but since it consists of sixteen step-like, overlapping, rectangular, mica plates, each 2 mm. shorter than the preceding and differing by one-quarter wave length from it, the order may at once be known by the position of the wedge. After removing the mineral slide, if the Bertrand lens is inserted, the separation lines between the plates can be more distinctly seen.

The following table is adapted from that given by Fedorow:

Order.	Crossed Nicols.	Diff. in Wave Length.	Order.	Parallel Nicols.
1.	†gray. . . . .	0.000127 mm.	$\frac{1}{2}$	brownish yellow
1.	†pure white. . . . .	0.000255	$\frac{1}{2}$	dark violet-brown
1.	orange yellow. . .	0.000382	$1-\frac{1}{2}$	sky blue
1.	orange red. . . . .	0.000511	$1-\frac{1}{2}$	light yellowish
2.	blue. . . . .	0.000637	$1-\frac{1}{2}$	canary yellow
2.	green. . . . .	0.000765	$1-\frac{1}{2}$	yellowish orange
2.	yellow. . . . .	0.000892	$2-\frac{1}{2}$	intense violet blue
2.	orange-red. . . . .	0.001020	$2-\frac{1}{2}$	leek green
3.	indigo. . . . .	0.001147	$2-\frac{1}{2}$	chrome yellow
3.	smaragdite green	0.001275	$2-\frac{1}{2}$	light orange
3.	lemon yellow. . .	0.001402	$3-\frac{1}{2}$	pure violet
3.	orange. . . . .	0.001530	$3-\frac{1}{2}$	pure green
4.	violet-red. . . . .	0.001657	$3-\frac{1}{2}$	light yellowish
4.	grass green. . . .	0.001785	$3-\frac{1}{2}$	light orange
4.	greenish yellow.	0.001912	$4-\frac{1}{2}$	light reddish blue
4.	rose. . . . .	0.002040	$4-\frac{1}{2}$	light greenish

\* Zeitschrift für Krystallographie, vol. 25, 1895, pp. 349-351.

† These colors are difficult of determination between crossed nicols, but sharply determinable between parallel nicols.

(e) *By parallel nicols.* The lower orders of gray are difficult of determination between crossed nicols, but sharply determinable when the nicols are parallel, as may be seen from the table above.

(f) *With the Amann birefractometer.* This consists of an ocular containing a quartz wedge which can be moved, by means of a screw, across one half of the field of the microscope. The method of use is similar to that of the ordinary quartz wedge. The mineral section is turned until its *a* direction is at right angles to that in the instrument. The point at which the two tints are neutralized and darkness occurs can be read directly from a scale engraved on glass and which moves with the wedge. A cap nicol must be used with this instrument. If the mineral fragment is isolated or at the edge of the section, it can be brought under the clear glass part of the ocular and a direct comparison made with the colors of the wedge.

(g) *With a Babinet compensator.* This instrument consists of two quartz wedges cut to very acute and equal angles, and so arranged that the *a* direction of one coincides with the *c* direction of the other. The lower wedge is movable by means of a micrometer screw; the upper wedge is stationary and has engraved upon it a cross to serve as a location point. When set at zero, the two wedges compensate and the resulting dark band coincides with the cross, while on either side are similar parallel bands of colors.

On inserting a mineral section with its vibration directions parallel to those of the compensator, the black band is displaced. The amount of motion necessary to bring it back to the cross can be read by means of the micrometer screw and is a measure of the birefringence.

(h) *With the Michel-Lévy comparateur.* The interference colors obtained by means of a movable quartz wedge are projected, by means of a prism in this instrument, into the field of the microscope, and the interference color of the mineral is determined by direct comparison.

**Determination of the Relative Values of Two Vibration Directions.**

(That is, the positive (+) or negative (−) character of the elongation of a mineral section.)

The mineral section is rotated between crossed nicols in plane polarized light to extinction. The cross-hairs of the microscope now coincide with one of the axes of vibration, while the other is at right angles to it. The section is rotated  $45^\circ$ , bringing the axes to the same angle with the cross-hairs, and the interference color is at its maximum. A mica plate is now inserted between the crossed nicols at the same angle, thus having its optic axes parallel to those of the mineral. The effect of this is to raise or lower the interference color of the crystal section. The colors will rise in the scale (p. 10 and colored plate), when similar axes have the same direction, and will fall when different axes are superimposed. In the first case the retardation of the mica plate is added to that of the mineral, and acts as a thickening of the section; in the latter it is subtracted and acts as a thinning of the section. Knowing the direction of  $\alpha$  in the test plate, the relative positions of the directions of greater and less ease of vibration in the mineral section are known.

For thicker sections or strongly refracting crystals a gypsum plate or quartz or mica wedge may be used in a similar manner. A gypsum plate will produce an increase or decrease of a whole order. If a wedge of quartz or mica is inserted with its vibration directions at right angles to those in the mineral, the colors will descend in the scale until the vibrations neutralize each other and the field of the microscope becomes dark. A rotation of  $90^\circ$  will produce a rise in color.

When the direction of elongation of a mineral section approximately coincides with the axis of least ease of vibration ( $\epsilon$ ), the fragment is said to have **positive elongation**; when it approximately coincides with the axis of greatest ease of vibration ( $\alpha$ ), it has **negative elongation**.

If the direction of crystallographic  $c$  in uniaxial crystals, or the acute bisectrix in biaxial crystals, is known, then the above, of course, also serves to determine the (+) or (−) character of the crystal, as well as the elongation. The mineral is positive if  $\epsilon=c$  of uniaxial or the acute bisectrix of biaxial crystals, and negative if  $\alpha=c$  or the acute bisectrix.

*Determination of the character of elongation of a mineral showing a wedge-shaped edge and, consequently, bands of interference colors between crossed nicols.* It

often happens, in a rock slide, that some fragments of the mineral, whose elongation is to be determined, have edges which are not at right angles to the section. Where these edges occur at the periphery or in a cavity, they may be used to determine the elongation. If a

quartz wedge is pushed forward the whole scale of Newton's colors will appear in a succession of bands which move in the same direction as the wedge when the axes correspond, and in the opposite direction when they do not. (Fig. 5.)

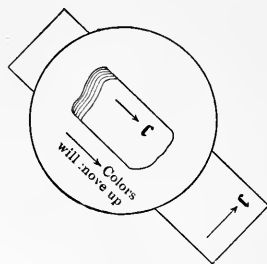


FIG. 5.—The vibration directions in the mineral and wedge are at right angles to each other.

### Dichroism.

As the velocity of light varies in uniaxial crystals when it vibrates parallel or at right angles to the vertical axis, so there may be different degrees of absorption in these directions.

### Pleochroism.

The alteration of color, in some minerals, with the alteration of the direction of transmission of the polarized ray, is called **pleochroism**. As biaxial minerals have three indices of refraction ( $\alpha$ ,  $\beta$ ,  $\gamma$ ), so also may they have different degrees of absorption in different directions, which is shown in polarized light when these directions are parallel to the plane of the polarizer. Since the absorption is dependent upon the wave

length of light, it may be that in one direction the red is more strongly absorbed than the blue, consequently, in transmitted light, such minerals show different colors when the light vibrates in different directions. The degree of absorption is usually written  $a > b > c$ , or  $a = b > c$ , etc.; the absorption axes being assumed to coincide with the axes of vibration, although they do not always do so.

### *Examination in Convergent Polarized Light.*

Convergent light is used to separate uniaxial from biaxial crystals, to determine dispersion and the optical character, and to separate isotropic minerals from anisotropic ones cut at right angles to the optic axis.

#### **Interference Figures.**

**Appearance in uniaxial minerals.** (a) *Sections normal to the optic axis.* These show a symmetrical dark cross, due to

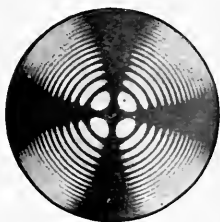


FIG. 6.—A uniaxial interference figure.

the extinction of all rays coinciding with the planes of the nicols, and a series of concentric rings, alternating light and dark in monochromatic light and showing the colors of the spectrum in white light (Fig. 6). During a rotation of the stage the arms of the dark cross remain stationary. An increase in the strength of the double refraction or an increase in the thickness of the slide causes the cross and rings to become more sharply defined and the distance between the rings to decrease.

(b) *Sections oblique to the optic axis.* The center of the cross will appear farther and farther toward the edge of the field of the microscope as the section is more and more oblique to the optic axis (Figs. 7-18), finally being entirely outside the field. On rotating the stage, the center of the cross (the point of emergence of the optic axis) will move in the same direc-



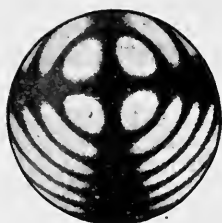


FIG. 7.

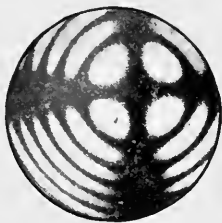


FIG. 8.



FIG. 9.



FIG. 10.



FIG. 11.



FIG. 12.

FIGS. 7-12.—Uniaxial interference figures. The center is toward the edge of the field of the microscope.



FIG. 13.



FIG. 14.

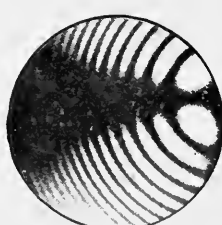


FIG. 15.

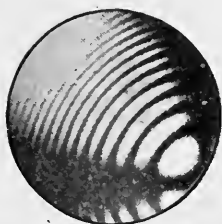


FIG. 16.

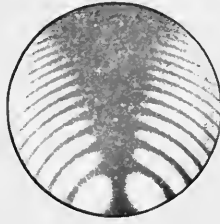


FIG. 17.

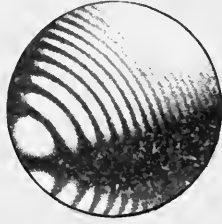


FIG. 18.

FIGS. 13-18.—Uniaxial interference figures. The center is beyond the field of the microscope.

tion as the stage, but the arms will always remain parallel to the cross-hairs. To distinguish such figures from biaxial interference figures showing only part of a bar, one needs only remember that in uniaxial minerals the arms remain parallel to the cross-hairs during the rotation of the stage.

(c) *Sections parallel to the optic axis.* These sections show hyperbolæ which are very similar to those seen in biaxial figures, except that they do not appear in the field until the stage is nearly in the  $90^\circ$  position, and then they move in, form a cross, which is seldom sharp, and very rapidly move out again in the direction of the principal axis. During the greater part of the rotation, therefore, they do not show in the field of the microscope.

The optic axis lies in the direction toward which the hyperbolæ leave the field. Its position may also be determined by the appearance of the interference colors. If the stage is turned  $45^\circ$  from the position in which the bars form a cross, there will appear a certain interference tint in the center of the field. Outward from this center there will be a fall in the color scale toward the quadrants in which the optic axis lies and a rise in the other two quadrants. This holds good for both (+) and (-) crystals. (Figs. 19 and 20.) In thick plates, or in

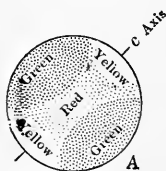


FIG. 19.

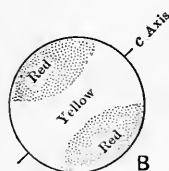


FIG. 20.

FIGS. 19-20.—Interference figures of uniaxial minerals cut parallel to the optic axes. Fig. 19. Quartz (+). Fig. 20. Apatite (-).

minerals having high double refraction, this is only observable at the center; beyond that, there is a uniform rise in colors.

**Appearance in biaxial minerals.** (a) *Sections perpendicular to the acute bisectrix.* These show in white light between crossed nicols, when the axial angle is less than the field of the micro-

scope and the plane of the axes coincides with the cross-hairs, a black cross, and a series of colored curves (Fig. 24). At the point of emergence of each optic axis there will be a dark spot, and surrounding it a number of rings which unite at the center and form lemniscate curves around the two. On rotating the stage the cross dissolves into two hyperbolæ whose poles are the loci of the optic axes. These bars revolve in an opposite direction from the stage and always have their convex side toward the acute bisectrix. (Figs. 21-26.) The



FIG. 21.



FIG. 22.



FIG. 23.



FIG. 24.



FIG. 25.



FIG. 26.

FIGS. 21-26.—Biaxial interference figures. The section is cut at right angles to the acute bisectrix.

smaller the axial angle, the nearer together will be the loci of the optic axes, until finally the figure approaches the form given by a uniaxial mineral. When the axial angle is large neither of the loci will show, but the biaxial character can be determined by the movement of the bars.

(b) *Sections perpendicular to the obtuse bisectrix.* When the axial angle is not too large, these show similar figures to those seen in sections cut at right angles to the acute bisectrix.

Generally, however, the angle is large, the axes suffer total reflection from the lower side of the section, and no figure is seen.

(c) *Sections inclined to the bisectrix.* More and more of one eye and less of the other is seen as the section is more and more



FIG. 27.



FIG. 28.

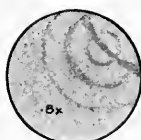


FIG. 29.

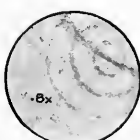


FIG. 30.



FIG. 31.



FIG. 32.



FIG. 33.



FIG. 34.



FIG. 35.

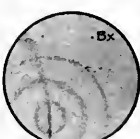


FIG. 36.

FIGS. 27-36.—Biaxial interference figures. One optic axis and the acute bisectrix emerge within the field of the microscope.



FIG. 37.

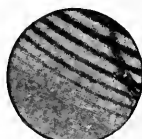


FIG. 38.



FIG. 39.

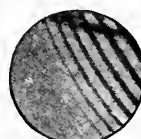


FIG. 40.

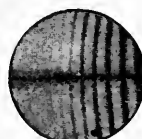


FIG. 41.



FIG. 42.



FIG. 43.



FIG. 44.

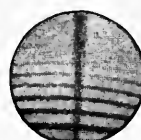


FIG. 45.

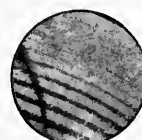


FIG. 46.

FIGS. 37-46.—Biaxial interference figures. The optic axes and the acute bisectrix emerge beyond the field of the microscope.

inclined. The convex side of the hyperbola is always toward the acute bisectrix and the arm rotates in a direction opposite to the turning of the stage. (Figs. 27-36 and 37-46.)

(d) *Sections at right angles to an optic axis.* These show nearly circular concentric curves crossed by a single dark bar which is straight whenever it is parallel to the planes of vibration of the nicols (Fig. 47). Upon rotating the stage, this bar changes to a slightly curved hyperbola with its convex side toward the acute bisectrix. Sometimes the arm is not sharply defined, especially when the section is not quite at right angles to the optic axis, and the arm may show as a bar, straight on one side and concave on the other (Fig. 48). The straight side is here toward the acute bisectrix. Upon turning the stage the arm rotates in the opposite direction.

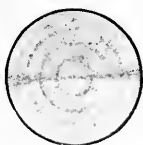


FIG. 47.—Biaxial interference figure showing the emergence of an optic axis in the center of the field of the microscope.

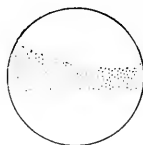


FIG. 48.—Biaxial interference figure with the optic axis emerging beyond the field of the microscope.

Since light is dispersed in all biaxial crystals, a section can be actually at right angles to an optic axis only for a given color. The dispersion is generally so slight, however, that it may be overlooked, and one will see, in white light, a series of colored rings, whose tints will differ from the pure colors of Newton's scale more and more with increasing dispersion.

(e) *Sections parallel to the plane of the optic axes.* Sections cut parallel to the plane of the optic axes (perpendicular to the  $b$  axis) may be recognized in parallel polarized light by the fact that they show the highest interference colors. In convergent light they show figures similar to those shown by uniaxial crystals parallel to the optic axis. The hyperbolæ come in from the sides very rapidly, darken the field, and, upon a very slight rotation, immediately disappear in the direction of the acute bisectrix. When the field is dark the axes  $a$

and  $\epsilon$  are parallel to the cross-hairs. Becke\* has shown how one may determine the position of the acute bisectrix in this section. The method has already been described in reference to uniaxial figures (p. 26). The line uniting the quadrants containing the lower colors is the direction of the acute bisectrix, ( $\alpha$ ) in (-) and ( $\epsilon$ ) in (+) minerals. When the axial angle approaches  $90^\circ$  the color variation becomes indistinct; when  $2V=90^\circ$  it disappears.

The above may be verified by using the gypsum plate, with red of the first order, as a mineral section.

In sections cut parallel to the plane of the optic axis the optical character of the mineral may also be determined by observing whether the acute bisectrix is  $\alpha$  or  $\epsilon$ .

**Locating the points of emergence of the optic axes.** (a) *In uniaxial minerals.* When the eye of a uniaxial figure is beyond the field, there is no difficulty in determining its position, as may be seen in Figs. 7 to 18. It is at the junction of the two bars.

(b) *In biaxial minerals.* The appearance of a biaxial figure, when the eyes are beyond the field of the microscope, is given in Figs. 37 to 46. (1) When the bisectrix is within the field, it is to be noted that the hyperbolæ come in from the sides upon which the eyes are located and disappear toward them. (2) When the bisectrix is outside the field of the microscope, the arm of only one hyperbola will be seen; the other arm, and consequently the bisectrix, is upon the convex side of the bar. (Figs. 27 to 46, and Fig. 48.)

**The axial angle.** *Apparent and true optic angle.* When a section of a biaxial mineral, cut normal to the acute bisectrix, is turned to the  $45^\circ$  position between crossed nicols, the distance between the hyperbolæ, that is, between the points of emergence of the optic axes, is a measure of the angle between these axes. Owing to the different rates of vibration for differ-

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\* Tschermak's Mineralogische und petrographische Mittheilungen, vol. 16, 1897, p. 181.

ent rays, a section normal to one color will not be normal to the others, except in the orthorhombic system. If, however, the section is cut to the mean color, the result will be approximately correct. In Fig. 49, which is a cross-section through a slide, the angle  $BOA$  is one half the true axial angle and is represented by  $V$ . Owing to the change in direction of the ray in passing into air, the observed angle,  $E$ , is  $BO'A'$ . If the axial angle is acute, it is represented by  $2E_a$  or  $2V_a$ ; if it is obtuse, by  $2E_o$  or  $2V_o$ .

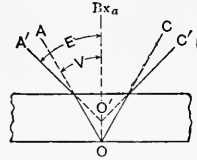


FIG. 49.—True and apparent axial angles.

*Measurement of the axial angle.* There are numerous methods for measuring the axial angle, but most of them are not applicable to the ordinary petrographical microscope, since the objective is too near the slide to permit turning about an axis.\* If the slide is turned about the point  $O'$  (Fig. 49), with the line at right angles to the axial plane as an axis, until the line  $O'C'$  coincides with the cross-hairs of the telescope of a goniometer, and is then turned until  $O'A'$  coincides, the angle through which the section has been turned is the apparent axial angle,  $2E$ .

In a thin section under the microscope the angle can be determined by measuring the distance between the points of emergence of the axes with a micrometer eyepiece. The slide is turned until the hyperbolæ are in the  $45^\circ$  position, after which the distance ( $2d$ ) between them is measured. The distance of the point of emergence of an optic axis from the bisectrix was shown by Mallard to be proportional to the sine of the angle which it makes with the axis of the microscope. Thus

$\sin E = \frac{d}{C}$ , in which  $E$  is half the axial angle in air,  $d$  half the distance between the hyperbolæ, and  $C$ , a constant for each lens combination, which may be determined by using a mica flake whose axial angle is known and substituting in the for-

\* A summary of methods for measuring the axial angle will shortly be published by Dr. Fred. E. Wright, in the *American Journal of Science*.

mula. By substituting these values in the equation  $\sin V = \frac{\sin E}{n'}$ , in which  $n'$  is the mean index of refraction of the mineral examined, the true value of the axial angle ( $2V$ ) may be found.

If the section examined is not exactly at right angles to the plane of the optic axes, by the use of a tilting stage, it may be tipped until the bisectrix coincides with the axis of the microscope. There are numerous appliances which may be used for this purpose: **Klein's Universaldrehapparat**, **Fedorow's Universaltisch**, or a simple apparatus described by **Jaggar**.\*

The determination of the axial angle may be made graphically by the **Mallard-Becke method**. With a camera lucida the hyperbolæ appearing in the field are transferred to a sheet of paper and, knowing the value of  $C$ , the angle may be plotted and measured.

**Schwarzmann's axial angle scale** may be used for the determination of  $2E$ . This is a scale made upon logarithmic principles, and from it the angle can be read direct. It consists of two parts, of which the lower is adjusted to the constant of a certain combination of lenses. The distance,  $D$ , upon the upper scale, will be found directly above the value of  $2E$  for that distance. A different scale is used for each different lens combination.

### Dispersion of the Optic Axes.

As light passing through a prism is separated into the spectrum, on account of the difference in wave lengths of different-colored rays, so the value of  $V$  and the loci of the hyperbolæ in the interference figures will vary with different wave lengths of light. This variation produces what is called the **dispersion of the optic axes**, and is recognized under the microscope by a change in the position of the loci of the axes. To indi-

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\* *American Journal of Science*, 3, 1897, p. 129.



cate this dispersion, red and violet rays are considered.  $\rho$  is used to indicate red light and  $\nu$  to indicate violet light. Thus  $\rho < \nu$  shows that the dispersion of red is less than that of violet.

**Optical characteristics of the different systems.** (a) *Orthorhombic system.* In the orthorhombic system the three vibration axes ( $\mathbf{a}$ ,  $\mathbf{b}$ ,  $\mathbf{c}$ ) coincide with the crystallographic axes ( $a$ ,  $b$ ,  $c$ ), and any of the former may coincide with any of the latter. These positions being fixed, the color distribution will be symmetrical with reference to both bisectrices, although the optic angle may differ. The plane of the optic axes always lies in one of the pinacoids. There may be two cases:  $\rho > \nu$ , in which the axes are more dispersed for red than for violet, and  $\rho < \nu$ . Fig. 50 shows a section through an orthorhombic crystal with

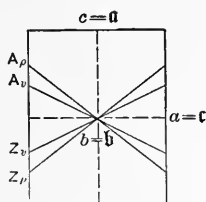


FIG. 50.—Section through an orthorhombic crystal with  $\rho > \nu$ .

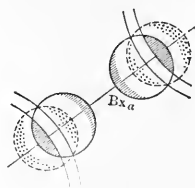


FIG. 51.—Dispersion in an orthorhombic crystal with  $\rho > \nu$ . (The solid lines and hatchures may be colored blue, the dotted lines, red.)

the optical scheme  $\rho > \nu$ . Fig. 51 shows its dispersion in the interference figure. The dispersion is always least for that color which occurs within the circle nearest the bisectrix and which touches the concave side of the hyperbole when the section is in diagonal position. The colors in the two eyes are symmetrical with reference to the bisectrix.

(b) *Monoclinic system.* In the monoclinic system only the  $b$  axis coincides with an optic axis, and this shows no dispersion. The other two optic axes lie in the (010) plane and are at right angles to each other and to the one coinciding with  $b$ . There are three kinds of dispersion.

1. *Inclined.* In this the axial plane is parallel to (010) and  $b=b$ . The color distribution will be symmetrical to the line joining the loci of the hyperbolæ, but not in the other direction. The intensity of the eyes will be different. One eye will be less intense, larger, and oval; the other, smaller, intense, and round. The distribution of color will depend upon the amount of dispersion of the axes. If this is slight the colors will be symmetrical with reference to the bisectrix. (Fig. 52,

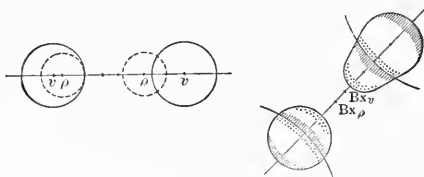


FIG. 52.—Inclined dispersion in a monoclinic crystal. Gypsum, with  $\rho < \nu$ . (The solid lines and hatchures may be colored blue; the dotted lines and dotted areas, red.)

gypsum  $\rho < \nu$ .) With stronger inclined dispersion (Fig. 53, diopside  $\rho > \nu$ ), like colors will occur upon the same sides of the loci of the axes. The smaller eye, also, will be farther from the cross-bar at the bisectrix, and one hyperbola will be broader than the other.

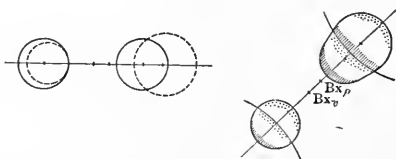


FIG. 53.—Inclined dispersion in a monoclinic crystal. Diopside,  $\rho > \nu$ . (The solid lines and hatchures may be colored blue; the dotted lines and dotted areas, red.)

2. *Horizontal.* Crystallographic  $b$  is the obtuse bisectrix, the acute bisectrix is in the clinopinacoid and the plane of the optic axes is perpendicular to (010). The axial figure will be symmetrical to the (010) plane only, and the figure must be dispersed as in Fig. 54. The colors will be symmetrical only to the one plane.

3. *Crossed.* Crystallographic  $b$  is the acute bisectrix and will remain unchanged for all colors of light. The obtuse bisectrix and the  $b$  axis are dispersed. There are no planes, but only a point of symmetry. This point is the locus of the acute bisectrix, which is the axis of symmetry (Fig. 55).

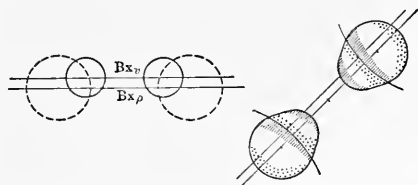


FIG. 54.—Horizontal dispersion in a monoclinic crystal.  $\rho < \nu$ .

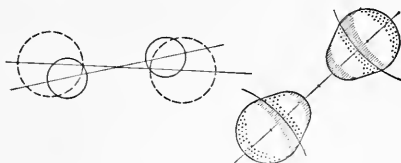


FIG. 55.—Crossed dispersion in a monoclinic crystal  $\rho > \nu$ . (The solid lines and hatchures may be colored blue; the dotted lines and dotted areas red.)

*c. Triclinic system.* All of the vibration axes are dispersed in the triclinic system and the distribution of the colors in the interference figures is unsymmetrical throughout.

### Determination of the Optical Character of the Crystal in Convergent Polarized Light.

In convergent polarized light the character of a mineral can be determined by inserting a mica or gypsum plate, or a quartz or mica wedge, above the interference figure.

**Uniaxial crystals.** (a) *Quarter undulation mica plate.* Upon inserting a quarter undulation mica plate, with its  $a$  direction parallel to the elongation, above the mineral and at  $45^\circ$  to the cross-hairs, the dark cross will separate, for positive minerals, as shown in Fig. 56 *a*. In negative minerals the position of the dark spots will be reversed, as Fig. 56 *b*. If the mica plate

has  $\epsilon$  for its long direction, the phenomenon will be reversed. The separation of the cross in the interference figure is caused by the one fourth wave length ( $\frac{1}{4}\lambda$ ) decrease in the rays vibrating in the first and third quadrants, and the increase by  $\frac{1}{4}\lambda$  in

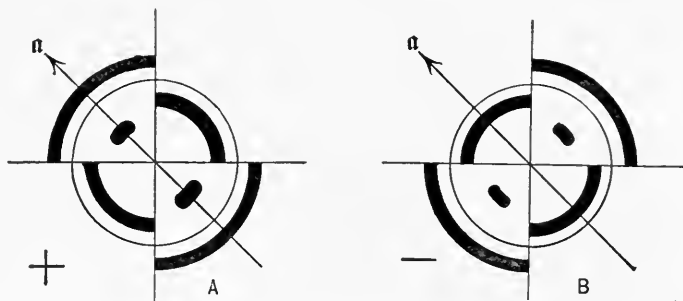


FIG. 56.—Determination of the optical character of a uniaxial crystal with the mica plate. (a) Positive. (b) Negative.

the others. The direction of the arrow upon the mica plate is usually that of  $\epsilon$ . The method for testing this direction is given in Part IV.

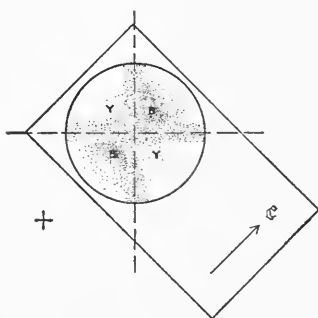


FIG. 57.

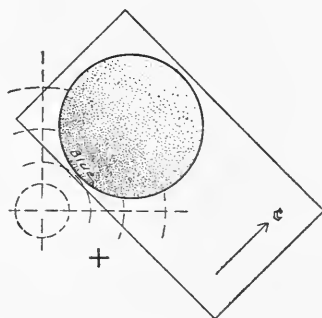


FIG. 58.

FIG 57.—Determination of the optical character of a uniaxial crystal with the gypsum plate. Quartz (+).

FIG. 58.—Determination of the optical character of a uniaxial crystal with the gypsum plate when the center of the cross is beyond the field of the microscope. Quartz (+).

(b) *Gypsum plate giving red of the first order.* If the double refraction of a mineral is weak, or the section is very thin, the mica plate is unsatisfactory, and a gypsum plate having a

thickness of 0.055 mm. and giving the first-order red may be used in a similar manner. With the  $\alpha$  direction parallel to the elongation of the gypsum plate, positive crystals will be raised to blue in the second and fourth quadrants and reduced to yellow in the first and third (Fig. 57). For negative crystals the phenomenon is reversed. This accessory may be used even when the uniaxial cross is beyond the field of the microscope, by observing the location of the center (Fig. 58).

(c) *Quartz or mica wedge.* If the expansion or contraction of the rings cannot be recognized with a mica or gypsum plate, it can often be seen with a quartz or mica wedge. When such a wedge, with its  $\alpha$  direction parallel to its length, is pushed with the thin edge foremost between crossed nicols, the colors in the first and third quadrants move away from the center.

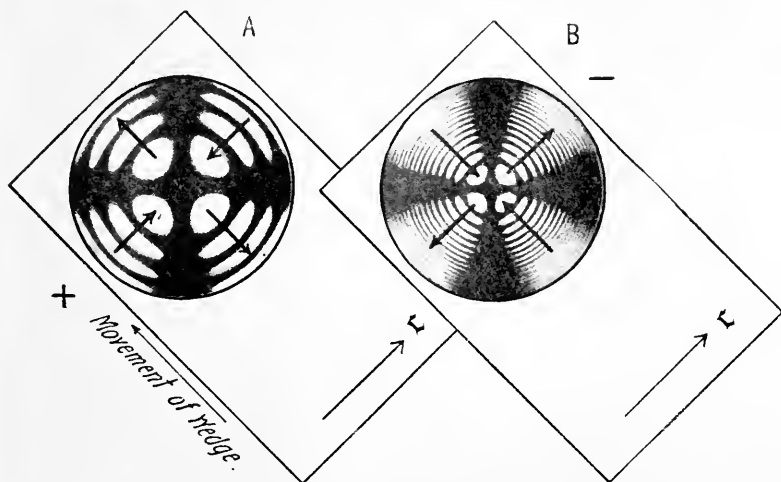


FIG. 59.—Determination of the optical character of a uniaxial crystal by means of a quartz wedge. (a) Quartz (+). (b) Calcite (-).

while in the second and fourth quadrants they move toward it (Fig. 59). With negative crystals or with  $\epsilon$  parallel to the long direction of the wedge, the phenomenon is of course reversed.

**Biaxial crystals.** (a) *Mica plate.* The phenomenon observed

upon inserting a quarter undulation mica plate above the interference figure of a biaxial mineral rotated until the hyperbolæ form a cross, is exactly the same as that seen in uniaxial minerals. For positive minerals the two black dots show along the direction of  $a$  of the mica plate and for negative minerals along the direction of  $c$ . (Fig. 56, *a*, *b*.) The mica plate is only of use when the hyperbolæ are well defined.

(*b*) *Gypsum plate.* Sections which show the emergence of the acute bisectrix but which show no isochromatic curves,

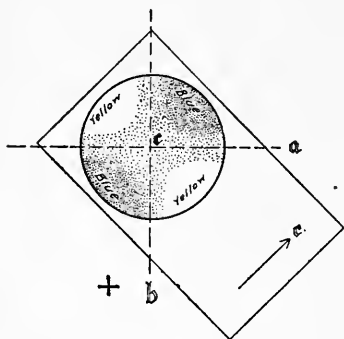


FIG. 60.—Determination of the optical character of a biaxial crystal in a section cut perpendicular to the acute bisectrix by means of the gypsum plate (+). (After Wülffing.)

when turned upon the stage so that the hyperbolæ form a cross, are in parallel position. If a gypsum plate with its  $a$  direction to the N.W., S.E., is now inserted, the center of the field will appear red, and, in positive minerals (Fig. 60), the N.E., S.W. quadrants will be colored blue, while the other two will be yellow. The position of blue and yellow will be reversed in negative minerals or if the gypsum plate has its elongation parallel to  $c$ .

Sections which show the emergence of only one axis may be determined in the same way. The convexity of the hyperbolæ is always toward the acute bisectrix; in the interference figure shown in Fig. 61 it is, therefore, to the N.W. By rotating the stage so that the acute bisectrix is in this position, and inserting a gypsum plate with its  $a$  direction also N.W., S.E., in positive minerals the concave side of the curve will be colored yellow, while in negative minerals it will be colored blue. (Fig. 62.)

In sections cut parallel to the plane of the optic axes (pp. 26 and 29), the direction of the acute bisectrix may first be determined, and then, in parallel light, the optical sign of the mineral.

(c) *Mica or quartz wedge.* For minerals which are thick, or which are strongly doubly refracting and which show several isochromatic curves, it is better to use a quartz or mica wedge

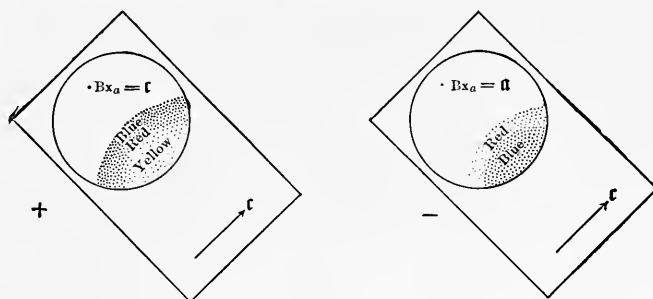
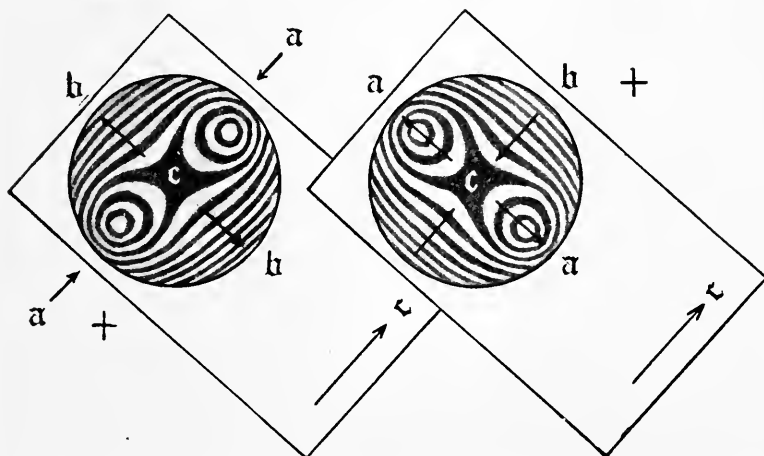


FIG. 61-62.—Determination of the optical character of biaxial crystals in sections showing the emergence of an optic axis by means of the gypsum plate. (After Wülfing.)

than a mica or gypsum plate. If, for example, a positive crystal (acute bisectrix= $c$ ) is placed under the microscope in the diagonal position (Fig. 63), and a quartz or mica wedge, with

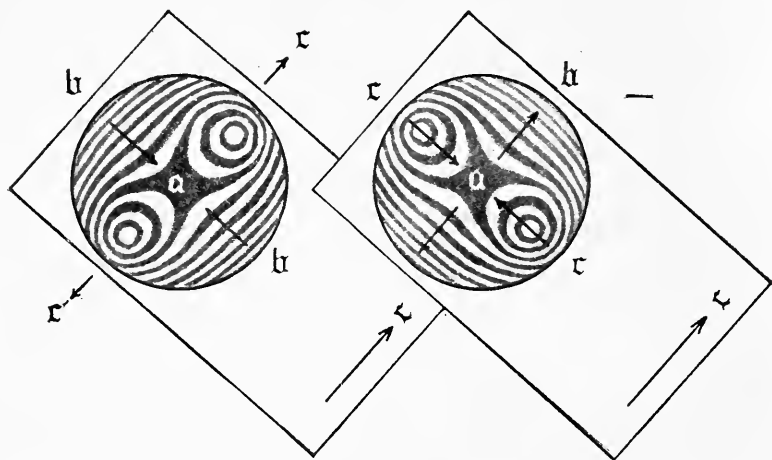


FIGS. 63-64.—Determination of the optical character of a positive biaxial crystal by means of a quartz wedge.

a parallel to its long direction, is inserted with the thin edge forward, the greatest ease of vibration in the slide and plate will be at right angles to each other, and the insertion of the

wedge has acted as a thinning of the plate. On shoving the wedge forward, the rings will become less numerous and will appear to move from the eyes toward the center and then out along the wedge. If the section is turned  $90^\circ$  (Fig. 64) the insertion of the wedge acts as a thickening of the section, the lemniscate curves will apparently move along the wedge to the center and then out toward the eyes. In either case, in a positive mineral, with  $a$  as the long direction of the wedge, the colors move out of the field in the long direction of the wedge and into the field at right angles to it.

For a negative mineral, or with  $r$  as the long direction of the wedge, the reverse movements will take place. (Figs. 65 and 66.)



FIGS. 65, 66.—Determination of the optical character of a negative biaxial crystal by means of a quartz wedge.

If instead of turning the figure to the  $45^\circ$  position, it is placed in the parallel position with the hyperbolæ bars forming a cross, and one considers the center of a uniaxial interference figure as the emergence of the two optic axes of a biaxial mineral infinitely close together, or looks upon the bisectrix as located in the center of a uniaxial cross, the phenomena indicating the positive or negative character are alike in both cases. For



example, with the quartz wedge inserted with its *a* direction parallel to the elongation of the wedge, in either the uniaxial cross (Fig. 67) or the biaxial figure in parallel position (Fig. 68), the colors will move away from the center at right angles to

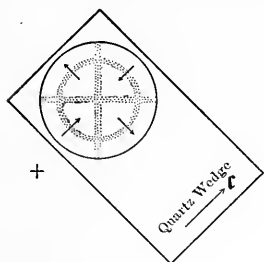


FIG. 67.

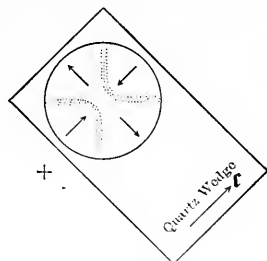


FIG. 68.

FIG. 67.—A positive uniaxial interference figure. The arrows indicate the movement taking place upon inserting a quartz wedge above the section.  
 FIG. 68.—A positive biaxial interference figure with the principal sections nearly corresponding to those of the nicols. The arrows indicate the movement taking place upon inserting a quartz wedge above the section.

the wedge in negative, and the reverse way in positive minerals.

The optical character of a mineral may be determined

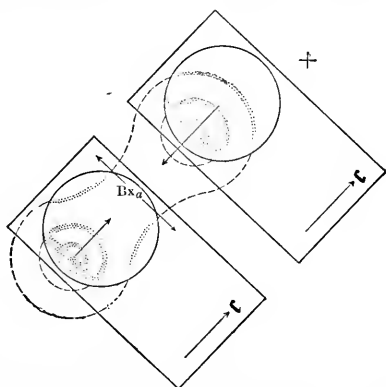
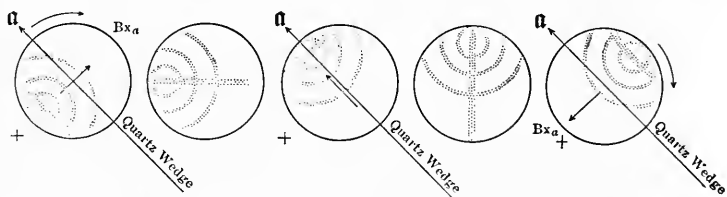


FIG. 69.—A biaxial interference figure showing the emergence of an optic axis. The arrow indicates the movement taking place upon inserting a quartz wedge above the section. The mineral is augite. (+).

with a quartz or mica wedge, even if the bisectrix emerges at the edge or entirely beyond the field of the microscope.

The case is exactly similar to that just described, and is best seen from the following figures which are given for a positive (augite) and a negative mineral (epidote). (Figs. 69-75.) The



FIGS. 70-74.—Movement of the left bar of Fig. 69 upon rotating the stage to the right, and movement of the colored rings upon inserting a quartz wedge.

arms in every case rotate in a direction opposite to that in which the stage is rotated. In these sections, which show only the emergence of one optic axis, account must carefully be taken of the position of the acute bisectrix, which is upon the convex

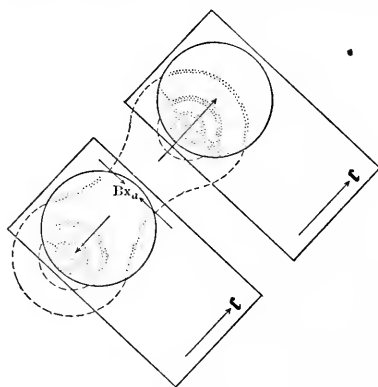


FIG. 75.

FIG. 75.—A negative biaxial interference figure. The arrows indicate the movement taking place upon inserting a quartz wedge above the section. Epidote. (-).

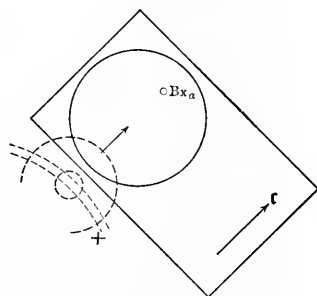


FIG. 76.

FIG. 76.—A positive biaxial interference figure. The arrows indicate the movement taking place upon inserting a quartz wedge above the section. Olivine. (+).

side of the hyperbola, otherwise there will be confusion between the left optic axis of the (+) mineral and the right axis of the (-) mineral and *vice versa*. (Figs. 69 and 75.)

When the point of emergence of the optic axis is entirely outside the field, it is sometimes possible to tell the position of the bisectrix by the curve of the bar (Fig. 48). In this case the optical character can be determined in the same way, as is shown by Fig. 76 for olivine.

### **Optical Anomalies.**

In certain minerals the optical behavior is different from what it should be according to the crystalline system. Thus, isomorphous crystals sometimes show double refraction (garnet, leucite, perovskite, etc.), or uniaxial minerals appear biaxial (quartz at times). The discussion of the cause of these anomalies is too long for this book, and the student is referred to Rosenbusch and Wülfing's *Mikroskopische Physiographie*, I<sub>1</sub>, pp. 356-359, where the subject is fully treated and many references are given.

### **Measurements Under the Microscope.**

**Measurement of enlargement.** The magnifying power of different combinations of objectives and oculars may be computed from the focal length of the combination, or may be directly measured by comparing the enlarged image of some object with its actual size. A small scale photographed on glass is placed upon the stage, the enlarged image is drawn by means of a camera lucida upon a sheet of paper and measured. The comparison may also be made by looking through the microscope with one eye and at a scale placed alongside with the other.

**Measurement of lengths.** A movable stage with micrometer screws working at right angles to each other serves best to measure actual size under the microscope. A micrometer eyepiece, whose divisions have been compared with a known scale for different combinations of lenses, may also be used.

**Measurement of thicknesses.** One may focus upon the top and bottom of a section and read the amount that the objec-

tive has been raised by means of the micrometer screw, applying a correction for refraction. If any mineral in the section is known, the thickness of the section, assuming it to have parallel faces throughout, may also be determined by the order of birefringence (cf., p. 19, and the colored plate in Part IV).

**Measurement of angles.** Angles may be measured under the microscope by moving the section until the point of the angle coincides with the cross-hairs of the microscope, bringing the two sides successively parallel to a cross-hair, and reading the angle through which the stage has been rotated.

**Measurement of the axial angle.** This subject has been fully treated above (p. 31).

## PART II.

### THE MINERAL GROUPS.

#### Spinel Group.

$R^{II}R^{III}_2O_4$ , where  $R^{II}$  is Mg, Zn, Fe, and  $R^{III}$  is Al, Fe, Cr, Mn.

##### SPINELS:

PRECIOUS,	$MgO \cdot Al_2O_3$ .	Colorless to pale red. light green, blue.
PLEONASTE,	$(Mg, Fe)O \cdot (Al, Fe)_2O_3$ .	Green.
HERCYNITE,	$FeO \cdot Al_2O_3$ .	Green.
GAHNITE,	$ZnO \cdot Al_2O_3$ .	Green.
PICOTITE,	$(Mg, Fe)O \cdot (Al, Fe, Cr)_2O_3$ .	Yellow or brown.
MAGNETITE,	$FeO \cdot Fe_2O_3$ .	Opaque, black.
CHROMITE,	$FeO \cdot Cr_2O_3$ .	Brown or thin edges.

Optical anomalies are common in some varieties:

Reactions: The precious varieties are not affected by acids; those that are rich in iron are decomposed by long treatment with HF or  $H_2SO_4$  or by fusion with alkali carbonates.

#### *Occurrence and alteration.*

*Spinel*s occur as original constituents in igneous rocks or secondary in metamorphic rocks, and are derived, according to Van Hise,\* from almandite, biotite, corundum, diaspore, garnet, gibbsite, olivine, pyrope. They alter to mica, serpentine, and talc.

*Magnetite* occurs as an original constituent in igneous rocks and is very common. As a metamorphic mineral it is derived,

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\* C. R. Van Hise: A Treatise on Metamorphism. Monograph XLVII, U. S. Geological Survey.

according to Van Hise, from actinolite, ankerite, arfvedsonite, augite, biotite, bronzite, diopside, garnet, grünerite, hematite, hornblende, hypersthene, ilmenite, marcasite, olivine, pyrite, pyrrhotite, sahlite, and siderite. It alters to hematite, limonite, and siderite.

*Chromite* occurs as an original or as a metamorphic mineral in magnesium-rich igneous rocks, often in connection with serpentine. It is, in many cases, derived from olivine.

### Garnet Group.

$R_3^{II}R_2^{III}Si_3O_{12}$ , where  $R^{II}$  is Ca, Mg, Fe, Mn, and  
 $R^{III}$  is Al, Fe, Mn, Cr, Ti.

**GROSSULAR:**  $Ca_3Al_2(SiO_4)_3$ . Colorless, light green. No optical anomalies. Is usually fresh; known to alter to calcite, quartz, zoisite. Occurs in marbles, and calcareous schists and gneisses.

**ALMANDINE:**  $Fe_3Al_2(SiO_4)_3$ . Red to brownish. No optical anomalies. Generally unaltered, though known to alter to chlorite, hypersthene, and spinel. Occurs in granites, andesites, schists, and gneisses.

**MELANITE:**  $Ca_3Fe_2(SiO_4)_3$ . Brown. Optical anomalies not seen on account of the deep color. Generally fresh. Occurs in basic eruptive rocks rich in alkali; nephelite-syenites, phonolites, tephrites, leucitophyres; also in serpentine.

**SPESSARTINE.**  $Mn_3Al_2(SiO_4)_3$ . Blood-red. Unaltered. Occurs in contact rocks, quartzites, and schists, and in lithophysæ in rhyolites.

**COMMON GARNET:** Mixture of the grossular, almandine, and melanite molecules. Red-brown to yellowish-red. Zonal structure and optical anomalies common. As a metamorphic mineral may be derived from vesuvianite. Alters to calcite, chlorite, epidote, hematite, hornblende, hypersthene, iron oxide, limonite, magnesite, magnetite, quartz, and siderite. Occurs in amphibolites, metamorphosed diabases, gabbros, pyroxenites, and in schists and gneisses.

**PYROPE:**  $\text{Mg}_3\text{Al}_2(\text{SiO}_4)_3$ . Blood-red. Kelyphite rims common. Alters to chlorite, enstatite, gibbsite, magnesite, quartz, serpentine, spinel, and talc. Occurs in peridotites and basalts.

**UWAROWITE:**  $\text{Ca}_3\text{Cr}_2(\text{SiO}_4)_3$ . Deep green, unaltered and with optical anomalies. Occurs in serpentines and is also found in marbles.

*Separation from other minerals.*

The strong index of refraction and insolubility in acids, united with isotropism, are characteristic of garnets. Spinels, only, resemble them, and from these they are separated by the presence of  $\text{SiO}_2$  in garnets. Spinels usually have octagonal outlines, while garnets generally show many-sided polygons.

**Sodalite Group.**

SODALITE,  $\text{Al}_2(\text{SiO}_4)_3 \cdot (\text{Al}, \text{Cl}) \cdot \text{Na}_4$ .

NOSELITE,  $\text{Al}_2(\text{SiO}_4)_3 \cdot \text{AlSO}_4 \cdot \text{Na} \cdot \text{Na}_4$ .

HAÜYNITE,  $\text{Al}_2(\text{SiO}_4)_3 \cdot \text{AlSO}_4 \cdot \text{Na} \cdot \text{CaNa}_2$ .

Sodalite, haüynite, and noselite occur as original constituents of igneous rocks, and are not known in schists and gneisses. Optical anomalies rare.

*Separation.*

*Sodalite* dissolves in  $\text{HCl}$ , and cubes of  $\text{NaCl}$  form upon drying the solution. If a few drops of a slightly acid solution of lead acetate are placed upon a thin section of sodalite, thin, flat needles of strongly doubly refracting lead chloride form over it.

Upon treating *noselite* and *haüynite* with  $\text{HCl}$ , gelatinous silica separates and they gelatinize in thin sections.

Upon drying a solution of noselite much  $\text{NaCl}$  and a little  $\text{CaSO}_4$  separates; from haüynite much  $\text{CaSO}_4$  separates.

*Separation from other minerals.*

The low indices of refraction distinguish the minerals of the sodalite group from other isotropic minerals except glass, fluorite, leucite, and analcite. Form and cleavage sepa-

rate them from glass; cleavage, lack of twinning, easy gelatinization and chemical reactions separate them from leucite and fluorite; form from analcite. Individual members of the group are separated by chemical means as given above.

### Carbonate Group.

*Calcite* and *aragonite* may be separated by Meigen's method.\* This has been modified by Panebianco, † who gives the following:

If calcite is boiled for one minute with a dilute cobalt nitrate solution, it becomes blue, and, after four minutes' boiling, lavender-blue. Aragonite, similarly treated, immediately becomes lilac and, with continued boiling, violet. The reaction for aragonite is very sensitive. In a mixture of one part of aragonite and nineteen parts of calcite, the color characteristic of the former will be produced.

*Calcite* and *dolomite* may be separated by observing the ease with which the powdered mineral is acted upon by cold HCl. They may also be separated by Lemberg's method.‡

A solution is made of

Aluminium chloride, dry. . . . .	4 parts
Logwood. . . . .	6 “
Water. . . . .	60 “

Boil half an hour, replacing the evaporating water, and filter.

If a few drops of this solution are placed upon a thin section of calcite and are allowed to stand for from five to ten minutes, and are then carefully washed off with water, the section will be colored violet; a section of dolomite will be unchanged.

Another method of separation is as follows:

If 1 gm. of calcite is boiled with 5 cc. of a 10% copper sul-

\* Meigen: Neues Jahrbuch, Centralblatt, 1901, p. 577.

† G. Panebianco: Rivista min. crist. ital., vol. 28, 1902, p. 5.

‡ Zeitschrift der deutschen geologischen Gesellschaft. Berlin, vol. xi, 1888, p. 357.



phate solution, the solution will become blue; with dolomite it will remain unchanged. If less calcite has been used than will replace the copper in the solution, upon adding ammonia to the filtrate the calcite solution will give no reaction, while the dolomite solution will become dark blue.

*Magnesite* is not affected by cold HCl; boiling HCl dissolves it with effervescence.

*Siderite* is soluble in HCl, and Fe is precipitated from a dilute solution, by adding ammonia.

### Scapolite Group.

Isomorphous mixtures of two molecules, not known to occur pure in nature:

$\text{Al}_2(\text{Si}_3\text{O}_8)_3\cdot\text{Na}_4(\text{AlCl}) = \text{Ma} = \text{Marialite molecule.}$

$\text{Al}_6(\text{SiO}_4)_6\text{Ca}_2(\text{CaOCa}) = \text{Me} = \text{Meionite molecule.}$

DIPYR,            A variety of mizzonite.

MIZZONITE,     $\text{Me}_1\text{Ma}_2$  to  $\text{Me}_1\text{Ma}_3$ .

WERNERITE,    $\text{Me}_3\text{Ma}_1$  to  $\text{Me}_1\text{Ma}_2$ .

MEIONITE,     Me.

Optical anomalies are rare and show a separation in the interference cross of basal sections.

### *Occurrence and alteration.*

The *scapolites* occur in crystalline limestones, often as the result of contact metamorphism in volcanic rocks, in crystalline schists, gneisses, and as an alteration product of feldspars. They alter to biotite, calcite, diaspore, epidote, gibbsite, kaolin, muscovite, quartz, and talc.

### *Separation.*

The basic mixtures from Me to  $\text{Me}_2\text{Ma}_1$  are decomposed by acids;  $\text{Me}_2\text{Ma}_1$  to  $\text{Me}_1\text{Ma}_2$  are but slightly affected, and marialite not at all.

Feldspars, cordierite, and zoisite have lower double refraction, are biaxial, and have different cleavage.

Quartz is (+), shows no cleavage, and has lower indices.

Prehnite and light-colored micas, with apparent uniaxial character, differ in cleavage.

Andalusite has lower double refraction and is biaxial.

### Olivine Group.

MONTICELLITE,  $\text{MgCaSiO}_4$ .

FORSTERITE,  $\text{Mg}_2\text{SiO}_4$ .

OLIVINE,  $(\text{Mg, Fe})_2\text{SiO}_4$ .

FAYALITE,  $\text{Fe}_2\text{SiO}_4$ .

#### *Occurrence and alteration.*

*Monticellite* occurs in the crystalline limestones. It is considered by many as isomorphous with olivine.

*Forsterite* rarely occurs in volcanic rocks. It is a mineral of dynamic and contact metamorphosed marbles, basic schists, and gneisses.

*Olivine* is usually an original mineral and occurs in the basic rocks, and as an accessory in basic schists, gneisses, and marbles. It alters to actinolite, anthophyllite, chromite, hematite, hercynite, iddingsite, limonite, magnesite, magnetite, opal, quartz, serpentine, siderite, spinel, and tremolite.

*Fayalite* occurs occasionally in volcanic rocks.

#### *Separation.*

*Monticellite* has a maximum birefringence of 0.017, while in the others it varies from 0.035 to 0.050. It is (-), while forsterite and olivine are (+). Fayalite has an index of 1.824 and a value of  $2V$  about  $50^\circ$ , while monticellite has  $n = 1.660$  and  $2V = 37.5^\circ$ .

*Forsterite* is (+). This separates it from all but olivine. Monticellite has lower birefringence, as given above. Occurrence is different from olivine, and it is generally colorless.

*Olivine* is (+). This separates it from all but forsterite,

which is a contact mineral of metamorphosed limestone. Monticellite has lower birefringence, as given above.

*Fayalite* is (-). This separates it from all but monticellite, which has much lower birefringence. Fayalite has  $2V=50^\circ$ , while monticellite has  $37.50^\circ$ . Olivine has  $2V=88^\circ$ , and has lower birefringence; 0.035 being the maximum, while the maximum in fayalite is 0.050.

### Humite Group.

CHONDRODITE,  $\text{Mg}_3[\text{Mg}(\text{OH},\text{F})]_2(\text{SiO}_4)_2$ .

HUMITE,  $\text{Mg}_5[\text{Mg}(\text{OH},\text{F})]_2(\text{SiO}_4)_3$ .

CLINOHUMITE,  $\text{Mg}_7[\text{Mg}(\text{OH},\text{F})]_2(\text{SiO}_4)_4$ .

The members of this group occur as masses in magnesian limestones and volcanic rocks bearing carbonates. Humite is orthorhombic; the other two are monoclinic with  $\beta$  equal to  $90^\circ$ , but with extinctions of  $25^\circ$ – $30^\circ$  in chondrodite, and  $7^\circ$ – $15^\circ$  in clinohumite. Humite may be mistaken for olivine, which it resembles in its alteration to serpentine. All of this group alter to bruceite and serpentine.

### Epidote Group.

ZOISITE,  $\text{Ca}_2(\text{AlOH})\text{Al}_2(\text{SiO}_4)_3$ .

PISTACITE,  $\text{Ca}_2(\text{AlOH})(\text{Al},\text{Fe})_2(\text{SiO}_4)_3$ .

PIEDMONTITE,  $\text{Ca}_2(\text{AlOH})(\text{Mn},\text{Al})_2(\text{SiO}_4)_3$ .

ORTHITE (Allanite),  $\text{Ca}_2(\text{AlOH})(\text{Al},\text{Ce},\text{Fe})_2(\text{SiO}_4)_3$ .

### *Occurrence and alteration.*

*Zoisite* is not known as an original constituent of igneous rocks. It occurs in schists, gneisses, and as an alteration of feldspar in the granitic rocks. It may be derived from corundum, diaspore, gibbsite, grossular, and plagioclase, and may alter to calcite, gibbsite, kaolin, and quartz.

*Pistacite* \* (green epidote) is rarely, if ever, an original con-

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\* The name *Pistacite* is used in the following pages for the green epidote, and *Epidote* as the group term.

stituent of igneous rocks. It occurs secondary in metamorphosed igneous rocks and in schists, gneisses, and marbles. It is derived from anorthoclase, augite, biotite, garnet, hornblende, microcline, orthoclase, plagioclase, and scapolites; and may alter to calcite, gibbsite, kaolin, limonite, and quartz.

*Piedmontite* replaces epidote, where Mn is an important constituent in the rocks.

*Orthite* is a minor constituent of acid and intermediate eruptive and plutonic rocks; and occurs in metamorphosed schists, gneisses, and marbles.

#### *Separation.*

*Zoisite* has a maximum birefringence of 0.009, while the other members of the group have a maximum of 0.032. It usually has abnormal interference colors.

*Piedmontite* has strong characteristic pleochroism in red and violet tones.

*Orthite*, being brown, differs from pistacite in color, is (+), and has an extinction of  $+36^\circ$ ,  $c:r$ , while pistacite has only  $+3^\circ$ .

#### **Mica Group.**

The micas may be divided into two classes:

1. The plane of the optic axes is normal to (010), and  $b = c$ .
  - a. ANOMITE. A magnesia-iron mica.
  - b. MUSCOVITE.
  - c. LEPIDOLITE.
  - d. PARAGONITE. The three latter are alkali micas.
2. The plane of the optic axes is parallel to (010), and  $b = a$ .
  - e. BIOTITE.
  - f. PHLOGOPITE.
  - g. ZINNWALDITE. These are all magnesia-iron micas.

#### *Separation from other minerals.*

The *micas* can be mistaken only for other silicates showing perfect basal cleavage. The birefringence, very low in basal sections, (0.000 in phlogopite, 0.003 in muscovite, and 0.008 in

biotite) combined with the high birefringence in sections showing cleavage (0.044 in phlogopite, 0.038 in muscovite, and 0.040 in biotite), is very characteristic.

Chlorite has very low double refraction.

Brittle micas are softer, and do not spring back into their former position on bending.

Margarite has an extinction angle of  $+6.5^\circ$ .

Talc has a very small value for  $2E$  ( $6^\circ$ – $20^\circ$ ). It does not become blue with cobalt solution, nor does it give reactions for K or Na. It has orientation like the first group,  $b=c$ , which, with its lack of color, separates it from the second group. Its hardness is 1.0.

#### *Separation of the micas.*

The optical orientation separates the two groups.

*Anomite* is separated from *b*, *c*, and *d*, by being strongly pleochroic.

*Muscovite* and *paragonite* do not give Li reaction, which separates them from lepidolite. From each other they can only be separated chemically, muscovite being the K mica and paragonite the Na mica.

In the second group:

*Zinnwaldite* is separated by its Li reaction from all the micas but lepidolite. From this the orientation separates it.

*Biotite* has strong pleochroism, while in phlogopite it is weak. The value of  $2E$  is always small in the latter, which is especially characteristic of the crystalline limestones and dolomites, often associated with pyroxene, amphibole, and serpentine. It has been described by Cross as occurring in madupite, orendite, and wyomingite, and by the writer, in mica peridotite.

#### **Chlorite Group.**

According to Tschermak the members of this group may be regarded as isomorphous mixtures of the amesite molecule  $(H_4Mg_2Al_2SiO_9)=At$ , and serpentine  $(H_4Mg_3Si_2O_9)=Sp$ .

PENNINE,	$\text{Sp}_3\text{At}_2$ to $\text{SpAt}$ .
CLINOCHLORE, (Ripidolite, Kobell).	$\text{SpAt}$ to $\text{Sp}_2\text{At}_3$ .
PROCHLORITE, (Chlorite, Kobell; Ripidolite, Rose).	$\text{Sp}_2\text{At}_3$ to $\text{Sp}_3\text{At}_7$ .
CORUNDOPHILITE,	$\text{Sp}_3\text{At}_7$ to $\text{SpAt}_4$ .
AMESITE,	$\text{SpAt}_4$ to $\text{At}$ .

### *Occurrence and alteration.*

*Chlorite* is very abundant as a secondary mineral, although not known as an original mineral. It occurs in altered igneous rocks, and in schists, gneisses, slates, etc.

*Pennine* and *clinochlore* are derived from biotite.

*Prochlorite* may be derived from almandine, anthophyllite, aragonite, augite, diopside, dolomite, epidote, fluorite, garnet, gypsum, haüynite, hornblende, noselite, sahlite, scapolites, tremolite, or zoisite.

*Amesite* may be derived from pyrope.

### *Separation from other minerals.*

The low birefringence, peculiar interference colors, and pleochroism are characteristic of the chlorite group.

## **The Zeolites.**

### Isometric.

ANALCITE,  $\text{NaAl}(\text{SiO}_3)_2 + \text{H}_2\text{O}$ .

### Tetragonal.

APOPHYLLITE,  $4\text{H}_2\text{Ca}(\text{SiO}_3)_2 + \text{KFl} + \text{H}_2\text{O}$ .

### Hexagonal.

HYDRONEPHELINE,  $\text{HNa}_2\text{Al}_3(\text{SiO}_4)_2 + 3\text{H}_2\text{O}$ .

CHABAZITE,  $(\text{Ca}, \text{Na}_2)\text{Al}_2(\text{SiO}_3)_4 + 6\text{H}_2\text{O}$ .

GMELINITE,  $(\text{Na}_2, \text{Ca})\text{Al}_2(\text{SiO}_3)_4 + 6\text{H}_2\text{O}$ .

### Orthorhombic.

THOMSONITE,  $2(\text{Na}_2, \text{Ca})\text{Al}_2(\text{SiO}_4)_2 + 5\text{H}_2\text{O}$ .

NATROLITE,  $\text{Na}_2\text{Al}_2\text{Si}_3\text{O}_{10} + 2\text{H}_2\text{O}$ .

### Monoclinic.

SCOLECITE,  $\text{Ca}(\text{AlOH})_2(\text{SiO}_3)_3 + 2\text{H}_2\text{O}$ .

EPISTILBITE,  $\text{H}_4\text{CaAl}_5(\text{SiO}_3)_6 + 3\text{H}_2\text{O}$ .

HEULANDITE,  $\text{H}_4\text{CaAl}_2(\text{SiO}_3)_6 + 3\text{H}_2\text{O}$ .

STILBITE,  $(\text{Na}_2, \text{Ca})\text{Al}_2\text{Si}_6\text{O}_{16} + 6\text{H}_2\text{O}$ .

PHILLIPSITE,  $2(\text{K}_2, \text{Ca})\text{Al}_2(\text{SiO}_3)_4 + 9\text{H}_2\text{O}$ .

HARMOTOME,  $\text{H}_2(\text{K}_2, \text{Ba})\text{Al}_2(\text{SiO}_3)_5 + 5\text{H}_2\text{O}$ .

LAUMONTITE,  $\text{H}_4\text{CaAl}_2\text{Si}_4\text{O}_{11} + 2\text{H}_2\text{O}$ .

The zeolites, with the exception of analcite, are always secondary minerals. They occur in almost every variety of eruptive rocks, especially in the more basic kinds, and also in altered sedimentary rocks. They are derived from many minerals, but especially from plagioclase, leucite, sodalite, etc., and generally occur as cavity fillings or in cracks.

### *Separation.*

*Analcite* is isotropic or has weak anomalous double refraction.

*Apophyllite*, *hydronephelite*, *chabazite* and *gmelinite* are uniaxial. Of these hydronephelite contains no Ca. Gmelinite gelatinizes with HCl; the others are decomposed with separation of flocculent silica. Chabazite generally occurs in rhombohedral forms, nearly cubical, while gmelinite has an angle of about  $68^\circ$ .

*Thomsonite* and *natrolite* are biaxial and have parallel extinction. Natrolite has a birefringence of 0.012 (Thomsonite 0.028),  $2V = 60^\circ - 62.5^\circ$  (Thomsonite  $87^\circ$ ).

The *monoclinic zeolites* are separated from the others by being biaxial and having inclined extinction. The extinction angle is above  $9^\circ$  in all but heulandite.

*Heulandite*, therefore, might be confused with the orthorhombic zeolites, thomsonite and natrolite. The elongation of heulandite is  $(-)$ , of natrolite  $(+)$ , of thomsonite  $(\pm)$ . Thomsonite has  $2E = 87^\circ$ . (Heulandite  $= 0^\circ - 55^\circ$ .) Birefringence: thomsonite  $= 0.028$ , heulandite  $= 0.007$ , natrolite  $= 0.012$ . The other monoclinic zeolites are separated from heulandite by the larger extinction angles.

Of the remaining monoclinic zeolites, *scolecite*, *epistilbite*, *stilbite*, and *laumontite* are  $(-)$ .

SCOLECITE,	$c: a = 17^\circ$ ,	$2E = 50^\circ - 60^\circ$	elongation $(-)$ .
EPISTILBITE,	$c: t = -9^\circ$ ,	$2E = 67^\circ - 83^\circ$ ,	" $(+)$ .
STILBITE,	$c: a = 5^\circ - 8^\circ$ ,	$2E = 52^\circ$ ,	" $(-)$ .
LAUMONTITE,	$c: t = +20^\circ$ ,	$2E = 54^\circ$ ca.,	" $(+)$ .

**Pyroxene and Amphibole Groups.****Pyroxenes.****Orthorhombic.**

ENSTATITE,	MgSiO <sub>3</sub>	<i>G</i> = 3.1-2.3
BRONZITE,	(Mg,Fe)SiO <sub>3</sub> Mg:Fe = 8:1 to 3:1	3.2-3.3
HYPERSTHENE,	(Mg,Fe)SiO <sub>3</sub> Mg:Fe = 3:1 to nearly 1:1	3.4-3.5

**Monoclinic.****I. With little or no aluminium.**

DIOPSIDE,	CaMgSi <sub>2</sub> O <sub>6</sub>	<i>G</i> = 3.2-3.38
DIALLAG, *		3.2-3.35
HEDENBERGITE,	CaFeSi <sub>2</sub> O <sub>6</sub>	3.5-3.58

**II. Aluminous.**

AUGITE,	Ca(MgFe)Si <sub>2</sub> O <sub>6</sub> with (MgFe)(AlFe) <sub>2</sub> SiO <sub>6</sub>	<i>G</i> = 3.3-3.5
ÆGIRITE-AUGITE,	Augite, rich in ægirite molecule	

**III. Alkali rich.**

ÆGIRITE,	NaFeSi <sub>2</sub> O <sub>6</sub>	<i>G</i> = 3.5-3.6
ACMITE,	NaFeSi <sub>2</sub> O <sub>6</sub>	3.5-3.6
SPODUMENE,	LiAlSi <sub>2</sub> O <sub>6</sub>	3.1-3.2
JADEITE,	NaAlSi <sub>2</sub> O <sub>6</sub>	3.33-3.35

**IV. Containing Ca.**

WOLLASTONITE,	Ca <sub>3</sub> Si <sub>3</sub> O <sub>9</sub>	<i>G</i> = 2.8-2.9
PECTOLITE,	NaHCa <sub>2</sub> Si <sub>3</sub> O <sub>9</sub>	2.74-2.88

*Separation.*

Pyroxenes differ from amphiboles in having a prismatic angle of 87° (amphiboles 124°), generally less perfect cleavage, and the crystals are usually stouter. The pleochroism, also, is generally weaker, often wanting, and the extinction angle is greater.

Monoclinic pyroxenes are separated from the orthorhombic by having inclined extinction. Acmite, ægirite, and pectolite have extinction angles usually less than 5°, and may be confused with the orthorhombic pyroxenes, but basal sections show the emergence of an axis in convergent light, while the orthorhombic pyroxenes show the emergence of a positive bisectrix. Ægirite has different pleochroism, much higher double refraction, and (−) elongation, while all the orthorhombic pyroxenes have (+) elongation.

---

\* Similar in composition to diopside, but often contains Al, sometimes in considerable amount: should then be classed with augite.



The mode of occurrence is about the same for all the orthorhombic pyroxenes.

Enstatite,	(+)	$2E=135^\circ$ .	Pleochroism: none.	Dispersion: $\rho < \nu$
Bronzite,	(+)	$106^\circ$ .	“ weak.	“ $\rho < \nu$
Hypersthene,	(-)	$85^\circ$ .	“ strong.	“ $\rho > \nu$

Bastite is (-),  $2E=20^\circ-90^\circ$ , pleochroism weak, dispersion  $\rho > \nu$ , birefringence weak. It is an alteration product of enstatite and bronzite.

Diopside,	$c: \epsilon = -39^\circ$	(+)	$2V=59^\circ$ .
Diallage.	$c: \epsilon = -39^\circ$	(+)	$2V=59^\circ$ and less.
Hedenbergite	$c: \epsilon = -44^\circ$	(+)	$2V=60^\circ$ .*
Augite.	$c: \epsilon = -45^\circ$ to $55^\circ$	(+)	$2V=60^\circ$ .
Ægirite-augite,	$c: \epsilon > -55^\circ < -87^\circ$ .	(+)	
Ægirite,	$c: a = -3^\circ$ to $-6^\circ$	(-)	$2V=62^\circ$ .
Acmite,	$c: a = -3^\circ$ to $-6^\circ$	(-)	†
Spodumene,	$c: \epsilon = -23^\circ$ to $-26^\circ$	(+)	$2V=54^\circ-60^\circ$ .*
Jadeite,	$c: \epsilon = -33.5^\circ$	(+)	$2V=72^\circ$ .
Wollastonite,	$c: a = +32^\circ$	(-)	$2V=69^\circ$ and less.*
Pectolite,	$c: a = -5^\circ$	(+)	$2V=60^\circ$ .‡

\* Birefringence is 0.015 to 0.019.

† “ “ 0.050.

‡ “ “ 0.038.

Others have birefringence from 0.015 to 0.029.

Pleochroism: Weak or wanting in all but ægirite-augite, ægirite, and acmite.

*Augite* is sometimes quite strongly pleochroic in purple tones.

*Ægirite* and *acmite* have different color and pleochroism.

As seen above the chief mode of separating the monoclinic pyroxenes optically is by means of the extinction angles, which are characteristic as shown in Fig. 77.

#### Occurrence.

*Diopside* occurs in marbles, especially in those that are magnesium rich, in the crystalline schists, pyroxene granites, diorites, and lamprophyres.

*Diallage* occurs in gabbros and related rocks, and in peridotites and the serpentines derived from them.

*Hedenbergite* is rather common in some nephelite-syenites and in other basic syenites.

*Augite* is the most common of the pyroxenes in the igneous rocks. It also occurs in metamorphosed sedimentary and igneous rocks.

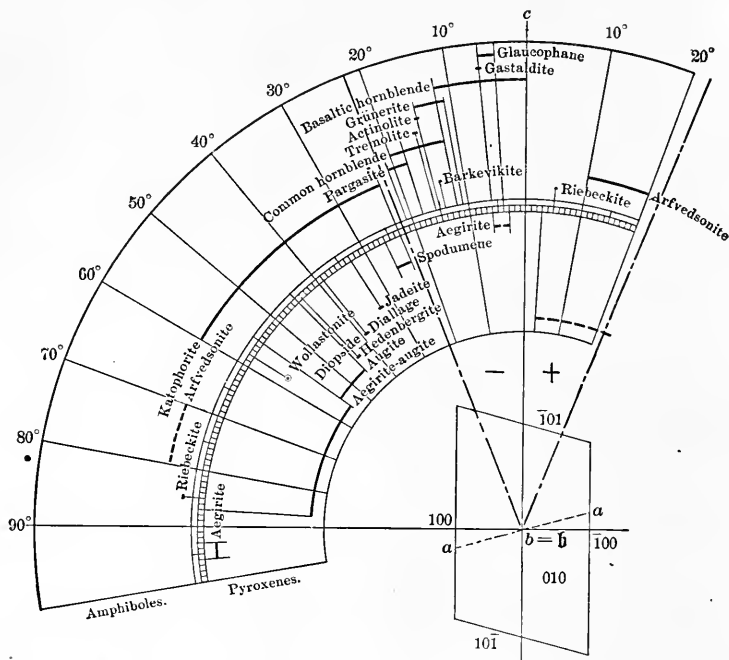


FIG. 77.—Maximum extinction angles in the Pyroxene and Amphibole groups. Solid lines indicate extinction angles from *c* to *r*; broken lines from *c* to *a*. The extinction angle in an amphibole is generally less than  $23^\circ$ ; in a pyroxene it is generally greater.

*Aegirite*, *aegirite-augite*, and *acmite* occur in eruptive rocks that are rich in sodium, especially in the nephelite-syenites, phonolites, leucitophyres, and in some granites and syenites.

*Spodumene* occurs in pegmatitic masses in granites, gneisses, and schists; sometimes as an accessory constituent in normal granite and gneiss.

*Jadeite* is not a common mineral. It occurs in metamorphosed hornblende schists and metamorphosed limestones.

*Wollastonite* occurs as a contact mineral in crystalline limestones, as a metamorphic mineral in calcareous rocks,—marbles, schists, gneisses,—and in calcareous inclusions in eruptive rocks.

*Pectolite* occurs in cracks and druses within many basic eruptive rocks.

### Amphiboles.

#### Orthorhombic.

ANTHOPHYLLITE,	$(\text{Mg,Fe})\text{SiO}_3$	$G = 3.1-3.2$
GEDRITE,	$(\text{Mg,Fe})_2\text{Si}_2\text{O}_6 \cdot \text{MgAl}_2\text{SiO}_6$	$3.1-3.2$

#### Monoclinic.

##### I. Containing little or no aluminium.

TREMOLITE,	$\text{CaMg}_3\text{Si}_4\text{O}_{12}$	$G = 2.9-3.1$
ACTINOLITE,	$\text{Ca}(\text{Mg,Fe})_3\text{Si}_4\text{O}_{12}$	$3.0-3.2$
GRÜNERITE,	$\text{FeSiO}_3$	$3.7f3$

##### II. Aluminous.

COMMON HORNBLende,	$\text{Ca}(\text{Mg,Fe})_3\text{Si}_4\text{O}_{12}$ with $(\text{Mg,Fe})_2(\text{Al,Fe})_4\text{Si}_2\text{O}_{12}$ and $\text{Na}_2\text{Al}_2\text{Si}_4\text{O}_{12}$	$G = 3.05-3.47$
--------------------	--	-----------------

PARGASITE.

KATOPHORITE, No analyses.

BASALTIC HORNBLende, Rich in iron and alkali molecules.

BARKEVIKITE.

##### III. Alkali rich.

###### a. Iron poor, light-blue color.

GLAUCOPHANE,	$\text{NaAlSi}_2\text{O}_6 \cdot (\text{Fe,Mg})\text{SiO}_3$	$G = 3.103-3.113$
GASTALDITE,	Contains more Al and less Fe.	

###### b. Iron rich, dark blue in color.

RIEBECKITE,	$\text{Na}_2\text{Fe}_2\text{Si}_4\text{O}_{12} \cdot \text{FeSiO}_3$	$G = 3.3$
ARFVEDSONITE,	$(\text{Na}_2\text{CaFe})_4\text{Si}_4\text{O}_{12} \cdot (\text{CaMg})_2(\text{AlFe})_4\text{Si}_2\text{O}_{12}$	$3.44-3.45$

### Separation.

Amphiboles differ from pyroxenes in having a prismatic angle of  $124^\circ$  (pyroxenes  $87^\circ$ ), generally more perfect cleavage, and the crystals are usually longer, thinner, and sometimes fibrous. The pleochroism is generally stronger and the extinction angle smaller.

The orthorhombic amphiboles are separated from the monoclinic by having parallel extinction; from other minerals all

the amphiboles are separated by their prismatic cleavage of  $124^\circ$ .

The orthorhombic amphiboles occur in metamorphic schists and gneisses, and as contact minerals. Anthophyllite often occurs as an alteration product of olivine in serpentines and in rocks of the gabbro and peridotite families. It has been described as an original mineral in a mica-peridotite dike from the East Indies.

Anthophyllite, Gedrite,		( $\pm$ ) (-)	$2V \geq 90^\circ$ , $2V = 57^\circ - 79^\circ$ ,	Dispersion $\rho \geq \nu$ . Dispersion $\rho > \nu$ .
	Extinction Angle.	Optical Char.	Axial Angle.	Pleochroism.
Tremolite,	$c:r = -16^\circ$	(-)	$2V = 87.5^\circ$ .	Non-pleochroic.
Actinolite,	$c:r = -15^\circ$	(-)	$2V = 80^\circ$ .	Faint, in green tones.
Grünerite,	$c:r = -11^\circ$ to $-15^\circ$	(-)	$2V = \text{large}$ .	Colorless; light brown.
Common hbl.,	$c:r = -12^\circ$ to $-20^\circ$	( $\mp$ )	$2V = 54^\circ$ to $84^\circ$ .	Strong; green and yellow tones.
Pargasite,	$c:r = -18^\circ$ to $-21^\circ$	(+)	$2V = 52^\circ$ to $60^\circ$ .	Green and yellow tones.
Katophorite,	$c:r = -23^\circ$ to $-60^\circ$	(+)	$2V = \text{small}$ .	Red and yellow tones.
Basaltic hbl.,	$c:r = 0^\circ$ to $-12^\circ$	(-)	$2V = 80^\circ$ .	Strong, green and brown tones.
Barkevikite,	$c:r = -14^\circ$	(-)	$2V = 54^\circ$ .	Brown tones.
Glaucophane,	$c:r = -4^\circ$ to $-6^\circ$	(-)	$2E = 85.5^\circ$ .	Colorless, yellowish green, blue.
Gastaldite,	$c:r = -6^\circ$	(-)	$2E = 70^\circ$ .	Ditto.
Riebeckite,	$c:r = -85^\circ$	( $\pm$ )	$2V = \text{unknown}$ .	Deep blue, light blue, yellowish green.
Arfvedsonite,	$c:r = +10^\circ$ to $+20^\circ$	( $\mp$ )	$2V = \text{large}$ .	Blue to greenish.

Riebeckite, arfvedsonite, and crossite have very low birefringence. This is high in basaltic hornblende and barkevikite, and between 0.016 and 0.026 in the others. Amphiboles are

determined chiefly by means of the extinction angles and pleochroism, which is colorless to greenish in the first three, in green and brown tones in the next five, and in tones of blue in the last four.

#### *Occurrence.*

*Tremolite*, *actinolite*, and *grünerite* occur in schists metamorphosed from carbonate rocks, especially those rich in magnesium and iron. In those in which the iron is not abundant, tremolite forms; where there is much ferrous iron, actinolite; and where iron is the chief or only carbonate, *grünerite*.

The *hornblendes*—*common*, *basaltic*, and *pargasitic*—are very common in igneous rocks, metamorphic schists, and gneisses.

*Katophorite* occurs in a tinguaita dike in Norway.

*Glaucophane* occurs in schists, especially those derived from basic rocks which formerly contained much sodium.

*Riebeckite* occurs in igneous rocks rich in iron and sodium, as alkali granites, and in metamorphosed sedimentary and eruptive rocks.

*Arfvedsonite* occurs in soda-bearing igneous rocks, as nephelite-syenites, phonolites, tinguaites, and pantellerites.

### THE DETERMINATION OF THE FELDSPARS.

Since the classification of a rock often depends upon the character of the feldspar occurring in it, its accurate determination is one of the problems of the petrographer. In the following pages are given the most common and the most helpful methods employed.

In all the members of the feldspar group the general characteristics are closely related. They are usually colorless, belong to the monoclinic or triclinic systems (although with close resemblance in angles, twinning, etc.), have a cleavage of  $90^\circ$  or nearly  $90^\circ$ , a hardness of between 6.0 and 6.5, and a specific gravity of from 3.84 in celsian, through 2.55 in orthoclase, to 2.76 in anorthite.

They may be classified as follows:

Monoclinic.	{	CELSIAN,	$\text{BaAl}_2\text{Si}_2\text{O}_8$	or	$\text{BaO} \cdot \text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2$
		HYALOPHANE,	$(\text{Ba}_n\text{K}_n)\text{Al}_2\text{Si}_4\text{O}_{12}$		
		ORTHOCLASE,	$\text{KAlSi}_3\text{O}_8$	or	$\text{K}_2\text{O} \cdot \text{Al}_2\text{O}_3 \cdot 6\text{SiO}_2$
		SODA-ORTHOCLASE,	$(\text{K}_n\text{Na}_n)\text{AlSi}_3\text{O}_8$		
Triclinic.	{	MICROCLINE,	$\text{KAlSi}_3\text{O}_8$	or	$\text{K}_2\text{O} \cdot \text{Al}_2\text{O}_3 \cdot 6\text{SiO}_2$
		ANORTHOCLASE,	$(\text{Na}_n\text{K}_n)\text{AlSi}_3\text{O}_8$		
		ALBITE,	$\text{NaAlSi}_3\text{O}_8$	or	$\text{Na}_2\text{O} \cdot \text{Al}_2\text{O}_3 \cdot 6\text{SiO}_2$
		OLIGOCLASE,			
		ALBITE,			
		LABRADORITE,			
		BYTOWNITE,			
		ANORTHITE,	$\text{CaAl}_2\text{Si}_2\text{O}_8$	or	$\text{CaO} \cdot \text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2$

### Cleavage.

All of the feldspars have a good cleavage parallel to (001) and another, nearly as good, parallel to (010). The angle between these cleavage lines varies slightly in the different feldspars.

Celsian, -	$001 \wedge 010 = 90^\circ$	$\beta = 64^\circ 58'$	$= 001 \wedge 100$
Hyalophane,	$001 \wedge 010 = 90^\circ$ for $\text{Ce}_1\text{Or}_2$	$\beta = 64^\circ 16'$	$= 001 \wedge 100$
Orthoclase,	$001 \wedge 010 = 90^\circ$	$\beta = 63^\circ 56' 46''$	$= 001 \wedge 100$
Microcline,	$001 \wedge 010 = 89^\circ 30'$ , circa.	$\beta = 116^\circ$	$= 001 \wedge 100$
Anorthoclase,	$001 \wedge 010 = 90^\circ 6' - 90^\circ 33'$	$\beta = 116^\circ 30'$	$= 001 \wedge 100$
Albite,	$001 \wedge 010 = 86^\circ 24'$	$\beta = 116^\circ 29'$	$= 001 \wedge 100$
Oligoclase,	$001 \wedge 010 = 86^\circ 32'$	$\beta = 116^\circ 22.5'$	$= 001 \wedge 100$
Andesine,	$001 \wedge 010 = 86^\circ 14'$	$\beta = 116^\circ 28.5'$	$= 001 \wedge 100$
Labradorite,	$001 \wedge 010 = 86^\circ 12'$	$\beta = 116^\circ 3'$	$= 001 \wedge 100$
Anorthite,	$001 \wedge 010 = 85^\circ 50'$	$\beta = 115^\circ 55.5'$	$= 001 \wedge 100$

As shown above, the angle between the crystallographic axes  $a$  and  $c$  varies between  $64^\circ$  and  $65^\circ$  in the monoclinic feldspars; and in the triclinic it remains within  $30'$  of  $116^\circ$ ; in either case the actual acute angle is not far from  $64^\circ$ .

### Chemical Composition.

Chemically the feldspars are silicates of aluminium with either potassium, sodium, calcium, or barium, or mixtures of these, and with iron and magnesium present in small amounts.

According to the law of Tschermak, the plagioclase feldspars are isomorphous mixtures of pure albite and anorthite mole-

cules. In a similar manner, according to Strandmark, the barium feldspars are isomorphous mixtures of pure celsian and orthoclase molecules.

The pure molecules are

Celsian,  $\text{BaAl}_2\text{Si}_2\text{O}_8 = \text{Ce.}$   
 Orthoclase,  $\text{KAlSi}_3\text{O}_8 = \text{Or.}$   
 Albite,  $\text{NaAlSi}_3\text{O}_8 = \text{Ab.}$   
 Anorthite,  $\text{CaAl}_2\text{Si}_2\text{O}_8 = \text{An.}$

Grouping the feldspars—

(After Strandmark.)

Celsian,	$\text{Ce}_1\text{Or}_0$ to $\text{Ce}_1\text{Or}_2$	contains from 16.5% to 39.5% BaO.
Hyalophane,	$\text{Ce}_1\text{Or}_2$ to $\text{Ce}_1\text{Or}_6$	“ “ 16.4% to 7.5% BaO.
Orthoclase,		“ “ 16.9% K <sub>2</sub> O.
Anorthoclase,	$\text{Or}_2\text{Ab}_3$ to $\text{Or}_1\text{Ab}_3$	“ “ 7.1% to 10.1% Na <sub>2</sub> O.

(After Tschermak.)

Albite series,	$\text{Ab}_1\text{An}_9$ to $\text{Ab}_8\text{An}_1$	contains from 11.79% to 10.27% Na <sub>2</sub> O
Oligoclase series,	$\text{Ab}_6\text{An}_1$ to $\text{Ab}_2\text{An}_1$	“ “ 10.01% to 7.63% Na <sub>2</sub> O
Andesine series,	$\text{Ab}_3\text{An}_2$ to $\text{Ab}_1\text{An}_3$	“ “ 6.91% to 6.56% Na <sub>2</sub> O
Labradorite series,	$\text{Ab}_1\text{An}_1$ to $\text{Ab}_1\text{An}_2$	“ “ 5.73% to 3.77% Na <sub>2</sub> O
Bytownite series,	$\text{Ab}_1\text{An}_3$ to $\text{Ab}_1\text{An}_1$	“ “ 2.82% to 1.55% Na <sub>2</sub> O
Anorthite series,	$\text{Ab}_1\text{An}_6$ to $\text{Ab}_0\text{An}_1$	“ “ 1.55% to 0.0 % Na <sub>2</sub> O

### Celsian.

Chemically varies from  $\text{Ce}_1\text{Or}_0$  to  $\text{Ce}_1\text{Or}_2$ .  $G = 3.84$ .

Monoclinic. (+). Cleavage: (001), (010), good.

Occurs in plates, prisms, and grains.

Orientation:  $b = \mathfrak{b}$ ,  $a : a = -62^\circ$ .

Colorless, non-pleochroic.

$\alpha = 1.584$ ,  $\beta = 1.589$ ,  $\gamma = 1.594$ .

$\gamma - \alpha = 0.010$ ,  $\gamma - \beta = 0.005$ ,  $\beta - \alpha = 0.005$ .

Carlsbad and Baveno twins occur.

2V increases with the increase in Ce; above  $90^\circ$  of Ce the optical character is positive, and the axial angle in pure celsian is  $94^\circ$ .

Soluble in HCl with gelatinization.

**Hyalophane.**

Chemically varies from  $\text{Ce}_1\text{Or}_2$  to  $\text{Ce}_1\text{Or}_6$ .

Monoclinic. (—). Cleavage: (001), (010), good.

Occurs in tablets, prisms, and grains.

Orientation:  $b = c$ ,  $a : c = -6^\circ$ .

Colorless, non-pleochroic.

$\alpha = 1.537$ ,  $\beta = 1.540$ ,  $\gamma = 1.542$ .

$\gamma - \alpha = 0.005$ ,  $\gamma - \beta = 0.002$ ,  $\beta - \alpha = 0.003$ .

Celsian and hyalophane show neither microcline structure nor polysynthetic twinning. They are, consequently, only likely to be confused with orthoclase and anorthoclase. From these they may be distinguished by the higher indices, larger extinction angles, higher specific gravities, and the chemical reactions of the barium feldspars. The different members of the barium feldspar series may be separated by their different specific gravities and their extinction angles on 010. (See Fig. 88.)

**Orthoclase.**

Chemically,  $\text{KAlSi}_3\text{O}_8$ .  $H = 6$ ,  $G = 2.54$ .

Monoclinic. (—). Cleavage: (001), (010), good.

Occurs in plates, prisms, and grains.

Orientation:  $b = c$ ,  $a : c = \pm 5^\circ$ . Extinction on (001) from (010) cleavage  $= 0^\circ$ , on (010) from (001) cleavage  $= \pm 5^\circ$ .

Colorless, non-pleochroic.

$\alpha = 1.519$ ,  $\beta = 1.523$ ,  $\gamma = 1.525$ .

$\gamma - \alpha = 0.006$ ,  $\gamma - \beta = 0.002$ ,  $\beta - \alpha = 0.003$ .

Dispersion:  $\rho > \nu$ , very plain.

$2V = 70^\circ - 80^\circ$ ,  $2E_{na} = 120^\circ$  ca.

**Twinning.** *Carlsbad law.* The most common form of twinning is according to the Carlsbad law, in which the vertical axis is the twinning axis and the composition plane is a plane parallel to the  $c$  axis, usually (010). The twins are turned  $180^\circ$  with respect to each other (Fig. 86). In the (001): (100) zone the



extinction is parallel to the (010) cleavage and to the twinning line. When the twinning line shows on the (010) face, it makes an angle of  $63^\circ 57'$  ( $\beta$ ) with the (001) cleavage and of  $\pm 21^\circ$  with the extinction of each individual. ( $c:b = 19^\circ - 23^\circ$ , Fig 85.) In this zone, as the sections depart from (010) and approach (100), the angle of the cleavage with the twinning line naturally increases

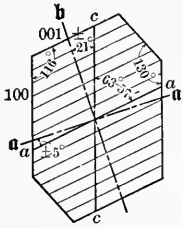


FIG. 78.

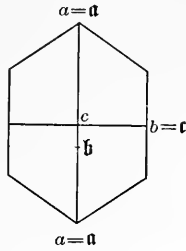


FIG. 79.

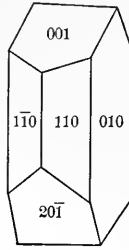


FIG. 80.

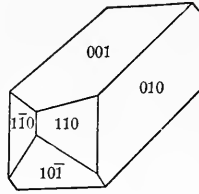


FIG. 81.

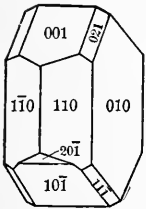


FIG. 82.

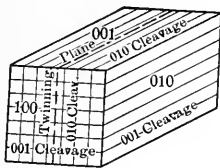


FIG. 83.

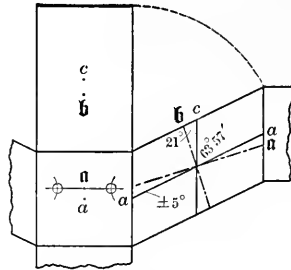


FIG. 84.

FIG. 78.—The (010) plane of an orthoclase crystal.

FIG. 79.—The (001) plane of an orthoclase crystal.

FIGS. 80–82.—Simple orthoclase crystals.

FIG. 83.—Simple orthoclase crystal showing cleavage lines and the position of the twinning plane in a Carlsbad twin.

FIG. 84.—A simple orthoclase crystal opened out to show the optical orientation.

from  $63^\circ 57'$  to  $90^\circ$ . The extinction angle also changes from  $21^\circ$  to  $90^\circ$ , the increase being slight at first, but, as the section approaches the (100) face, the change of extinction angle becomes very rapid. In any section in this zone the twinning line bisects the extinction angle and the cleavage.

The  $(001):(010)$  zone of one individual of a Carlsbad twin almost coincides with the  $(\bar{1}01):(010)$  of the other (Fig. 86). In all sections in this zone the cleavage cracks of one individual are parallel to the twinning line, and the extinction angle from this line varies from  $0^\circ$  on  $(001)$  to  $3^\circ$  to  $7^\circ$  ( $12^\circ$  in soda-orthoclase) on  $(010)$ . In the other individual the cleavage lines are at right angles to each other, and the extinction is parallel to them and to the twinning line. As the section approaches the  $(010)$  face, the extinction angle increases until it reaches  $\pm 48^\circ$  on  $(010)$ .

*Baveno law.* In Baveno twins the twinning axis is the line normal to  $(021)$ , which is the composition plane (Fig. 87). In sections at right angles to this plane the twinning line is diagonal

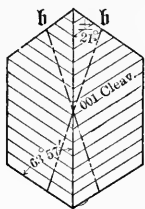


FIG. 85.

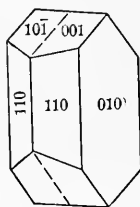


FIG. 86.

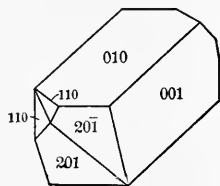


FIG. 87.

FIG. 85.—Extinction angle on the  $(010)$  face of a Carlsbad twin of orthoclase.

FIG. 86.—A Carlsbad twin of orthoclase.

FIG. 87.—A Baveno twin of orthoclase.

to the cleavage. The two parts extinguish at the same time and parallel to the cleavage, but the direction of  $\mathbf{a}$  in one individual is at right angles to  $\mathbf{a}$  in the other, and the interference figures lie at right angles to each other. In sections in the  $(001):(010)$  zone the cleavages of the two individuals are parallel to each other and to the twinning line. As the extinction angle in one increases from  $0^\circ$  to  $7^\circ$ , it decreases in the other in the same proportion.

*Manebacher law.* Manebacher twinning is comparatively rare. The  $(001)$  plane is the composition plane and the twinning axis is a line at right angles to it.

The low indices and low double refraction separate orthoclase and sanidine from the barium and plagioclase feldspars. As seen in Fig. 88, the indices of refraction are lower than

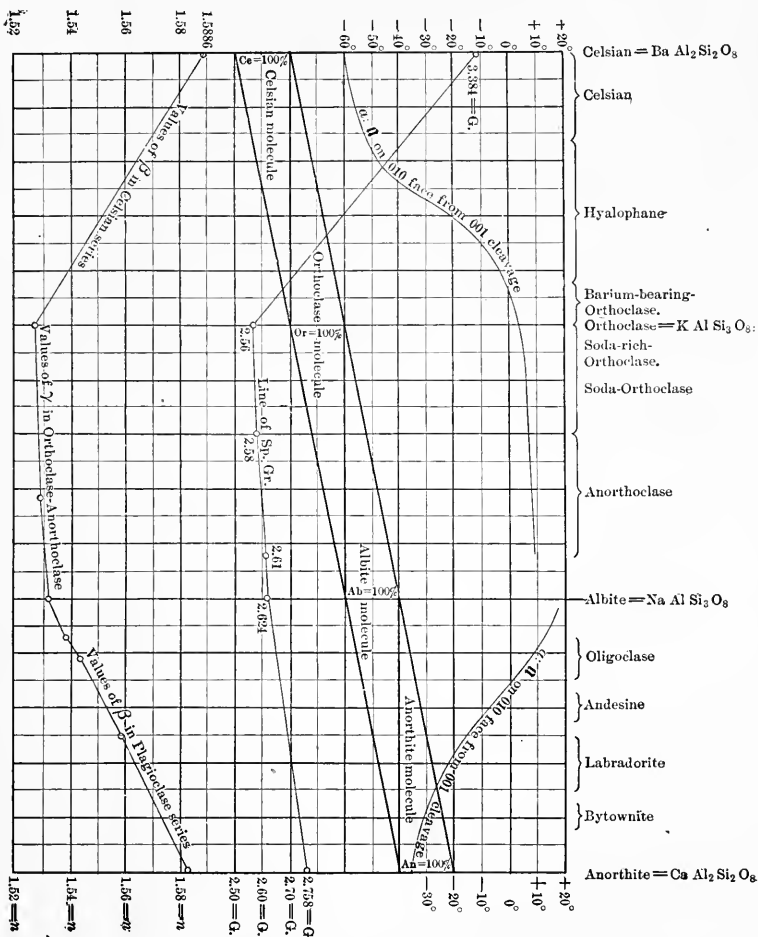


FIG. 88.—Diagram showing the comparative indices of refraction, specific gravities, chemical relations, and extinction angles on (001) faces of the feldspars from celsian to anorthite.

in any of the other feldspars, although anorthoclase, albite, and oligoclase-albite have indices lower than Canada balsam. From these they may be separated by the extinction

on (010) (see Fig. 95), upon which face it is lower than in orthoclase only in other feldspars with an index greater than Canada balsam. The polysynthetic twinning of the plagioclase feldspars usually distinguishes them, while in the barium feldspars, which are simply twinned like orthoclase, the values of the indices of refraction, double refraction, and specific gravity are entirely different.

### Sanidine.

Chemically, crystal habit, indices and double refraction like orthoclase.

Like orthoclase its optical character is (-).

Orientation: Like orthoclase or sometimes  $b=\mathfrak{h}$ ,  $a:\mathfrak{a}=+5^\circ$  ca.

Dispersion for  $b=\mathfrak{r}$ ,  $\rho>\nu$ ; for  $b=\mathfrak{h}$ ,  $\rho<\nu$ .

$2V$  much smaller than orthoclase. It varies from very small to  $0^\circ$ .

Carlsbad twinning frequent.

Distinguished from orthoclase by the orientation and the size of the optic angle; from the other feldspars in a manner similar to orthoclase.

### Microcline.

Chemically,  $\text{KAlSi}_3\text{O}_8$ ,  $H=6.0$ ,  $G=2.54$ .

Triclinic. (-). Cleavage: (001), (010), good.

Occurs in plates, prisms, and grains.

Orientation: Extinction on (010) =  $+5^\circ$ , on (001) =  $+16^\circ$ .

Colorless, non-pleochroic.

$\alpha=1.519$ ,  $\beta=1.523$ ,  $\gamma=1.526$ .

$\gamma-\alpha=0.007$ ,  $\gamma-\beta=0.003$ ,  $\beta-\alpha=0.004$ .

Dispersion:  $\rho>\nu$ ,  $2V=71^\circ-84^\circ$ .

Polysynthetic twinning, albite and pericline, almost invariably occurs.

*Twinning according to the pericline law.* In this the twinning axis is parallel to  $b$ , and the composition plane is parallel to the rhombic section. When the twinning is polysynthetic, the striations appear on the (010) face.

Separated from orthoclase, with which it may be confused when untwinned, by its extinction on (001) and (010); generally by its polysynthetic twinning with "grating" structure. The indices of refraction are lower than in the plagioclase and barium feldspars. From anorthoclase it is separated by the extinction angles on (001) and (010) and by the larger axial angle of microcline.

### Anorthoclase.

Chemically,  $\text{Or}_2\text{Ab}_3$  to  $\text{Or}_1\text{Ab}_6$ ,  $H=6.0$ ,  $G=2.56-2.61$ .

Triclinic. (-). Cleavage: (001), (010), good;  $\angle \pm 89^\circ$ .

Occurs in plates, prisms, and grains.

Orientation: Extinction on (010) =  $+4^\circ$  to  $+10^\circ$ ; on (001) =  $+1^\circ$  to  $+4^\circ$ .

Colorless, non-pleochroic.

$\alpha=1.523$ ,  $\beta=1.528$ ,  $\gamma=1.529$ .

$\gamma-\alpha=0.006$ ,  $\gamma-\beta=0.001$ ,  $\beta-\alpha=0.005$ .

Dispersion:  $\rho > \nu$ ,  $2V=43^\circ-53^\circ$ .

Sometimes has polysynthetic twinning, according to the albite and pericline laws, like microcline.

Separated from microcline by the extinction angles on (001) and (010) and by the smaller axial angle of anorthoclase.

Orthoclase has a larger axial angle.

The plagioclase feldspars have higher indices of refraction higher double refraction, and higher specific gravities.

### The Plagioclase Feldspars.

The special characteristics of the different members of the plagioclase group are given in the following pages, and no general descriptions of the individual members are necessary here. For their separation from the preceding feldspars, the distinguishing marks have already been given under those feldspars. Further than that, Fig. 88 graphically shows the relationships.

**Twinning.** *Albite law.* This is the most common form of twinning in the plagioclase feldspars. The twinning axis is nor-

mal to (010), and the lamellæ are consequently parallel to this plane. The twinning is usually polysynthetic, and the striations show on the (001) and the (100) faces. Very often this twinning

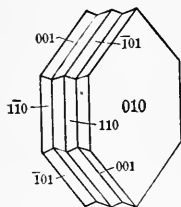


FIG. 89.—Albite and Carlsbad twinning combined.

is combined with the Carlsbad law, as in Fig. 89. When combined with the pericline law, the albite twinning may be recognized upon the (001) face, by the fact that the elongation of the twinning lamellæ lies in the direction of the axis of greatest ease of vibration ( $\alpha$ ); while in pericline twinning this length is in the direction of the ( $\epsilon$ ) axis.

**The determination of the plagioclase feldspars.** The following are the most important methods used for the determination of the different members of the plagioclase group:

1. By specific gravities.
2. By the optical character of the mineral.
3. By the relative indices of refraction of the feldspar and some known mineral with which it is in contact. (Becke.)
4. By the index of refraction, according to Schroeder van der Kolk's embedding method.
5. By the extinction angle on cleavage flakes parallel to (001). (Schuster.)
6. By the extinction angle on cleavage flakes parallel to (010). (Schuster.)
7. By the position of emergence of the bisectrix in (010) plates.
8. By the extinction angle in Carlsbad twins upon the (010) face. (Michel-Lévy.)
9. By the extinction angle on sections at right angles to both (001) and (010). (Becker and Becke.)
10. By the extinction angle on sections at right angles to either bisectrix. (Fouqué.)
11. By the extinction angle on sections at right angles to the optic normal ( $\beta$ ). (Fedorow.)

12. By the extinction angle on sections from the (001), (010) zone.
13. By the extinction angles on sections from the zone at right angles to (010). (Michel-Lévy.)
14. By the extinction angles on sections from the zone at right angles to (010), when the albite twinning is combined with Carlsbad twinning. (Michel-Lévy.)

1. *By specific gravities.* The specific gravity of minerals is an important constant in their determination, and is applicable to the separation of the feldspars. (Fig. 88.) For the purpose of determination, small fragments of the mineral should be separated under the microscope from the rock powder. Cleavage flakes can very often be obtained from the granular rocks or from the phenocrysts of effusive rocks. The value of the specific gravity is constant so long as the material used is pure and unaltered. Glassy inclusions or alterations to kaolin and zeolites reduce the value, while the inclusion of other minerals or the alteration to carbonates, mica, or saussurite increases it.

The following values are after Tschermak:

Orthoclase and microcline, sp. gr.	2.54-2.57
Anorthoclase series,	2.58-2.61
Albite series,	2.62-2.64
Oligoclase series,	2.64-2.66
Andesine series,	2.66-2.69
Labradorite series,	2.69-2.71
Bytownite series,	2.71-2.74
Anorthite series,	2.74-2.76

Day gives the following for artificial plagioclase feldspars:

Albite, Ab.....	2.605
Ab <sub>3</sub> An <sub>1</sub> .....	2.649
Ab <sub>2</sub> An <sub>1</sub> .....	2.660
Ab <sub>1</sub> An <sub>1</sub> .....	2.679
Ab <sub>1</sub> An <sub>2</sub> .....	2.710
Ab <sub>1</sub> An <sub>5</sub> .....	2.733
Anorthite, An. ....	2.765

2. *By the optical character of the mineral.* The optical character alone does not determine the kind of feldspar, but is of value when taken in connection with the index of refraction, birefringence, and other characteristics. According to the optical character, as determined in convergent polarized light, the two groups are as follows:

<i>Negative (−) character.</i>	<i>Positive (+) character.</i>
Hyalophane.	Celsian.
Orthoclase.	Albite.
Sanidine.	Oligoclase-albite.
Microcline.	Andesine.
Anorthoclase.	Labradorite.
Oligoclase.	
Bytownite.	
Anorthite.	

The values of  $2V$  and the optical characters are shown in Fig. 90.

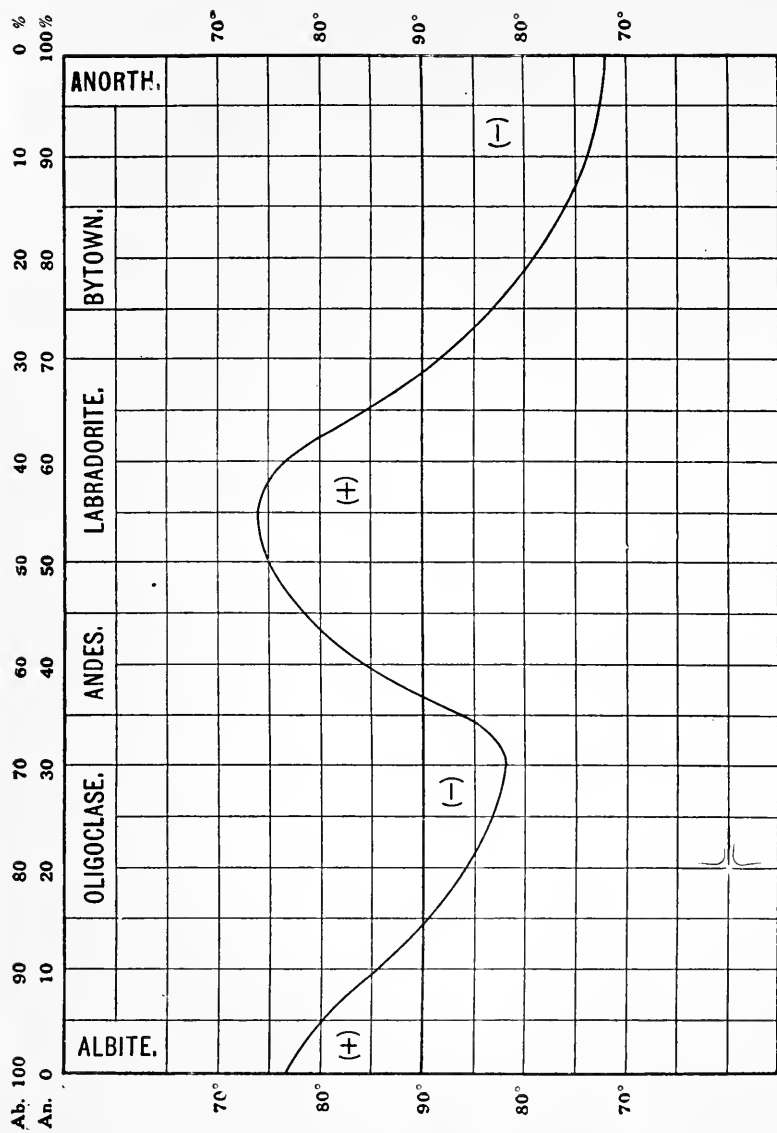
3. *By the relative indices of refraction of the feldspar and some known mineral with which it is in contact.* (Becke method.)

When the feldspar to be determined lies in contact with a known mineral, as quartz or nephelite, or even in contact with the Canada balsam, its relative index may be found by the movement of the Becke line. (See Part I, pp. 14, 15.)

Mean values of the indices are as follows:

Celsian,	$\alpha = 1.584$	$\beta = 1.589$	$\gamma = 1.594$
Hyalophane,	1.542	1.545	1.547
Orthoclase,	1.519	1.523	1.526
Sanidine,	1.521	1.525	1.525
Anorthoclase,	1.523	1.528	1.529
Albite,	1.529	1.532	1.539
Oligoclase-albite,	1.534	1.538	1.543
Oligoclase,	1.540	1.544	1.547
Andesine,	1.549	1.553	1.555
Labradorite,	1.555	1.558	1.563
Bytownite,	1.561	1.564	1.569
Anorthite,	1.575	1.583	1.588
Quartz,	$\omega = 1.544$		$\epsilon = 1.553$
Nephelite,	1.542		1.537



FIG. 90.—Curve showing the values of  $2V$  and the optical characters of the lime-soda feldspars.

Canada balsam.  $n = 1.542 +$  to  $1.55 -$ , depending upon the degree of heating which the balsam has undergone. It rarely rises higher than 1.545.

Select a place in the section where the extinction of the feldspar is parallel to that of the mineral with which it is in contact; its direction of greater ease of vibration will be parallel or at right angles to that of the other mineral. By the position of the Becke line the feldspars are thus divided into six groups, which are given by Rosenbusch as follows:

(Quartz:  $\omega = 1.544$ ,  $\varepsilon = 1.553$ .)

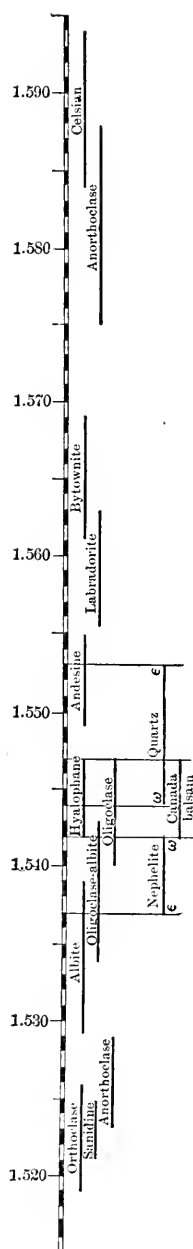
Group.	Parallel Position.	Crossed Position.	Feldspars.	
I.	$\omega > \alpha$ $\varepsilon > \gamma$	$\omega > \gamma$ $\varepsilon > \alpha$	Albite,	$\text{Ab}-\text{An}_8\text{An}_1$
II.	$\omega > \alpha$ $\varepsilon > \gamma$	$\omega \geq \gamma$ $\varepsilon > \alpha$	} Oligoclase,	$\text{Ab}_8\text{An}_1-\text{Ab}_3\text{An}_1$
III.	$\omega \geq \alpha$ $\varepsilon > \gamma$	$\omega < \gamma$ $\varepsilon > \alpha$		$\text{Ab}_3\text{An}_1-\text{Ab}_2\text{An}_1$
IV.	$\omega < \alpha$ $\varepsilon \geq \gamma$	$\omega < \gamma$ $\varepsilon > \alpha$	} Andesine,	$\text{Ab}_2\text{An}_1-\text{Ab}_3\text{An}_2$
V.	$\omega < \alpha$ $\varepsilon < \gamma$	$\omega < \gamma$ $\varepsilon \geq \alpha$		$\text{Ab}_3\text{An}_2-\text{Ab}_1\text{An}_1$
VI.	$\omega < \alpha$ $\varepsilon < \gamma$	$\omega < \gamma$ $\varepsilon < \alpha$	{ Labradorite, Bytownite, Anorthite.	$\text{Ab}_1\text{An}_1-\text{An}$

With the feldspars in any orientation adjacent to a basal section of quartz, or to a section parallel to  $c$ , which is that showing the brightest interference colors, the feldspars fall into two groups, according to whether the index is greater or less than 1.544 or 1.553.

After having separated the feldspars thus, they may be redivided by the optical character as in the preceding section.

Index $< \omega$ ( $= 1.544$ ) of quartz. (+)	Index $> \omega$ ( $= 1.544$ ) of quartz. (-)
Albite. Oligoclase-albite.	
	< Oligoclase (-) > Andesine. Labradorite.
	Bytownite. Anorthite.

FIG. 91.—Comparative mean indices of refraction of the feldspars, quartz, nephelite, and Canada balsam.



Index $< \varepsilon$ ( $=1.553$ ) of quartz. (+)	Index $> \varepsilon$ ( $=1.553$ ) of quartz. (-)
Albite.	
Oligoclase-albite.	
Oligoclase.	
$< \text{Andesine } (+) >$	Labradorite.
	Bytownite. Anorthite.

Where nephelite occurs in the rocks instead of quartz, that mineral may be used in a similar manner. Potassium feldspars and anorthoclase have all their indices lower than  $\varepsilon$  of nephelite.

(Nephelite:  $\omega = 1.542$ ,  $\varepsilon = 1.537$ .)

	In Parallel Position.	In Crossed Position.
Albite,	$\omega > \gamma$	$\varepsilon > \alpha$
Oligoclase-albite,	$\omega > \gamma$	$\varepsilon \geq \alpha$
Oligoclase,	$\omega \geq \gamma$	$\omega \geq \alpha$
Andesine,	$\omega < \gamma$	$\varepsilon < \alpha$
Labradorite,		
Bytownite,		
Anorthite,		
		$\omega < \alpha$
		$\varepsilon > \gamma$

With **Canada balsam** as a dividing line we have:

Albite is always less than Canada balsam.

Oligoclase-albite is usually less.

Oligoclase is the same.

Andesine, labradorite, etc., are always higher.

4. *By the index of refraction, according to Schroeder van der Kolk's embedding method.* This method was explained in Part I, pp. 15-18. Michel-Lévy, in his work on the feldspars,\* applied this method to their determination, but since some of Schroeder's fluids acted upon the minerals, he substituted Klein's solution diluted to different indices. He determined the index of refraction of the diluted solution by employing a series of sixteen minerals, of known indices, as indicators.

Instead of Klein's solution, mixtures of oils of different refractive indices, or of oil and benzene may be used. The latter has this disadvantage: the benzene evaporates rapidly, and the

\* Étude sur la détermination des feldspaths, etc., 1894, pp. 58-63.

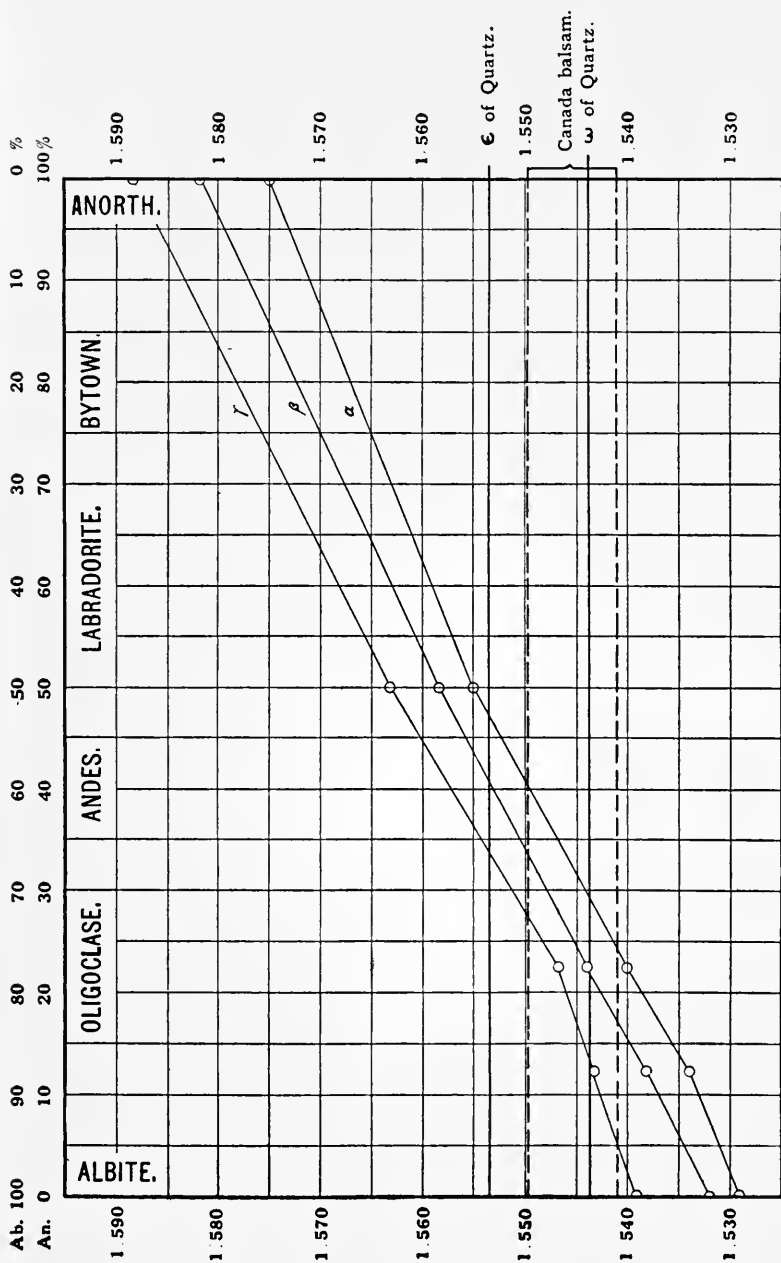


FIG. 92.—Curve showing the indices of refraction of the lime-soda feldspars. (Modified from Rosenbusch.)

index of the immersion fluid consequently rises. If one works rapidly and employs two indicators, one higher and one lower than the supposed index of the feldspar, by the changing of the index of the immersion fluid from low to high, the one fluid suffices for the determination. Wright\* has recently used mixtures of cedar and clove oils and clove and cinnamon oils.

A list of refractive indices of fluids is given in Part I, pp. 16-17, and the comparative indices of the feldspars in Fig. 92.

5.-6. *By the extinction angle on cleavage flakes parallel to (001) and (010).* All extinction angles in the feldspars are measured from the *a* axis. Max Schuster† first made the observation that the extinction angles of the feldspars are fixed within certain limits, and that these extinction angles correspond to definite chemical combinations. With a plagioclase crystal orientated as in Fig. 93, Schuster considered extinctions

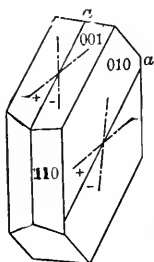


FIG. 93.

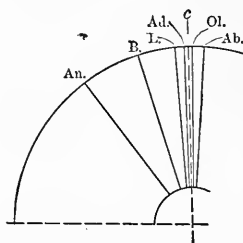


FIG. 94.

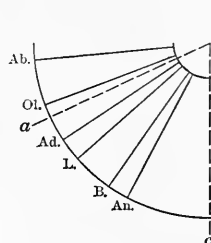


FIG. 95.

FIG. 93.—Positive and negative extinction angles in the feldspars.

FIG. 94.—Extinction angles on the (001) faces of the lime-soda feldspars.

FIG. 95.—Extinction angles on the (010) faces of the lime-soda feldspars.

on either face, when measured in the direction of the movement of the hands of a watch from the traces of the (010) and the (001) cleavage, as positive (+), and negative, when in the opposite direction. Schuster's values were:

\* American Journal of Science, Vol. XXI, 1906, pp. 361-363.

† Über die optische Orientierung der Plagioklase, Tschermak's Mineralogische und petrographische Mittheilungen, 3, 1880, p. 117.

	Ex. on (001)	Ex. on (010)
Albite, pure,	+4° to +5°	+19°
Oligoclase, Ab <sub>3</sub> An <sub>1</sub>	+1° 4'	+4° 36'
Andesine, Ab <sub>3</sub> An <sub>2</sub>	-2° 12'	-7° 58'
Labradorite, Ab <sub>1</sub> An <sub>1</sub>	-5° 10'	-16°
Bytownite, Ab <sub>1</sub> An <sub>3</sub>	-17° 40'	-29° 28'
Anorthite,	-37°	-36°

As modified by Mallard's formula and computed for percentages of albite and anorthite,\* they are:

	Ex. on (001)	Ex. on (010)	
Ab. . . . .	+ 4° 30'	+19°	} Albite and oligo- clase-albite
Ab <sub>95</sub> , An <sub>5</sub> . . . . .	+ 3° 57'	+16° 53'	
Ab <sub>90</sub> , An <sub>10</sub> . . . . .	+ 3° 21'	+14° 25'	
Ab <sub>85</sub> , An <sub>15</sub> . . . . .	+ 2° 40'	+11° 33'	} Oligoclase
Ab <sub>80</sub> , An <sub>20</sub> . . . . .	+ 1° 55'	+ 8° 17'	
Ab <sub>75</sub> , An <sub>25</sub> . . . . .	+ 1° 04'	+ 4° 36'	
Ab <sub>70</sub> , An <sub>30</sub> . . . . .	+ 0° 07'	+ 0° 36'	} Andesine
Ab <sub>65</sub> , An <sub>35</sub> . . . . .	- 0° 57'	- 3° 41'	
Ab <sub>60</sub> , An <sub>40</sub> . . . . .	- 2° 22'	- 7° 58'	
Ab <sub>55</sub> , An <sub>45</sub> . . . . .	- 3° 34'	-12° 08'	} Labradorite
Ab <sub>50</sub> , An <sub>50</sub> . . . . .	- 5° 10'	-16° 00'	
Ab <sub>45</sub> , An <sub>55</sub> . . . . .	- 7° 01'	-19° 29'	
Ab <sub>40</sub> , An <sub>60</sub> . . . . .	- 9° 08'	-22° 32'	} Bytownite
Ab <sub>35</sub> , An <sub>65</sub> . . . . .	-11° 35'	-25° 12'	
Ab <sub>30</sub> , An <sub>70</sub> . . . . .	-14° 22'	-27° 29'	
Ab <sub>25</sub> , An <sub>75</sub> . . . . .	-17° 54'	-29° 28'	} Bytownite-anor- thite and anor- thite
Ab <sub>20</sub> , An <sub>80</sub> . . . . .	-21° 05'	-31° 10'	
Ab <sub>15</sub> , An <sub>85</sub> . . . . .	-24° 56'	-32° 38'	
Ab <sub>10</sub> , An <sub>90</sub> . . . . .	-28° 58'	-33° 54'	
Ab <sub>5</sub> , An <sub>95</sub> . . . . .	-33° 03'	-35° 01'	
An. . . . .	-37°	-36°	

\* Tschermak's Mineralogische und petrographische Mittheilungen, 5, 1882.

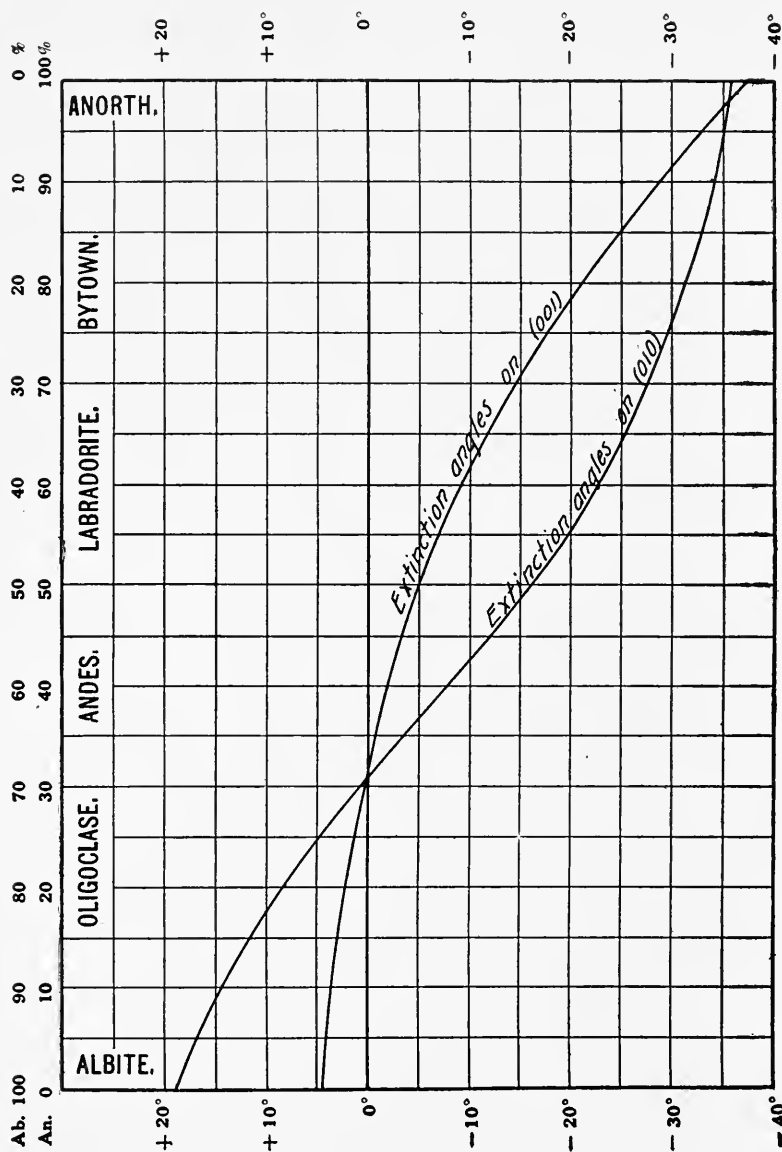


Fig. 96.—Extinction angles on the (010) and (001) faces of the lime-soda feldspars. (From the diagram constructed by Rosenbusch after the values of Max Schuster as modified by Mallard's formula.)



These are graphically represented in Fig. 96, from which it can be seen that there are upon the (001) face both positive (+) and negative (−) values up to  $5^\circ$ , making the feldspars, giving lower extinction angles, indeterminable unless the orientation of the section is known. Upon the (010) face there will be confusion if the extinction angle is less than  $19^\circ$ .

*How to recognize the (001) face.* These plates cannot be recognized in random thin sections of unknown feldspars, and one is obliged to obtain cleavage flakes. A fragment of the rock is crushed, not ground, in an iron or agate mortar, the powder is passed through a sieve with meshes of 0.5 mm., the dust floated off in water, the dark constituents separated by means of a heavy solution, and the remainder sorted under the microscope. A large part of the feldspar will be found to be in cleavage flakes along (001) and (010). Only flakes of less than 0.5 mm. in thickness and with parallel faces, which may be recognized by their uniform interference tints, are of use. The (001) flakes show albite twinning, while those along (010) do not. In the (001) sections the extinction is measured from the twinning lamellæ, in the (010) sections it is measured from the (001) cleavage.

*How to recognize the (010) face.* Upon the (010) face the albite twinning lamellæ are wanting; those according to the pericline law are sometimes seen. The crystal form (Fig. 97) is often shown in outline or by the zonal growth. The (001) cleavage is usually distinct, and is best seen when the diaphragm below the stage of the microscope is partially closed. In the acid feldspars the elongation is nearly parallel to *a*. The extinction is positive or negative, according to its direction from *a*, as shown in the figure and as explained above.

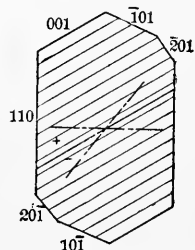


FIG. 97.—A (010) cleavage flake of plagioclase.

7. *By the position of emergence of the bisectrix in (010) plates.* In convergent light the different feldspars show different posi-

tions of emergence of the bisectrix in (010) plates. In air they are as follows:

In albite the inclination is small and the bisectrix is positive.

In oligoclase the bisectrix is nearly normal to the face.

In andesine the inclination is nearly  $20^\circ$  to the top and left.

In labradorite, upon the left face, the axis is not in the field; only part of a bar, part of one system of axial rings, and a small part of the lemniscate curves appear.

In bytownite the appearance is the same as in labradorite, except that no lemniscate curves show.

In anorthite the axis emerges at the edge of the field.

8. *By the extinction angle in Carlsbad twins upon the (010) face* (Michel Lévy).\* The extinction angles of Carlsbad twins showing upon the (010) face are particularly characteristic. The twinning line bisects the extinction angle of the two in-

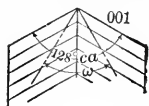


FIG. 98.—The (010) face of a Carlsbad twin of plagioclase.

dividuals ( $\omega$ ) and also their (001) cleavages, which make an angle of approximately  $128^\circ$  with each other (Fig. 98). Albite twinning does not show upon the (010) face, unless the section is slightly inclined from this direction. In the values given below for the angles between the two extinctions, it is immaterial whether the crystal shows a simple Carlsbad twin or polysynthetic albite twinning in combination with the Carlsbad twin, provided the direction of the section is not far from (010).

Albite,	$\text{Ab}_{95}\text{An}_5$	$\omega = 166^\circ$
Oligoclase-albite,	$\text{Ab}_{86}\text{An}_{14}$	$= 152^\circ$
Oligoclase,	$\text{Ab}_{75}\text{An}_{25}$	$= 130.5^\circ$
Andesine,	$\text{Ab}_{63}\text{An}_{37}$	$= 110.5^\circ$
Labradorite,	$\text{Ab}_{50}\text{An}_{50}$	$= 90.5^\circ$
Bytownite,	$\text{Ab}_{25}\text{An}_{75}$	$= 64.5^\circ$
Anorthite,	$\text{Ab}_0\text{An}_{100}$	$= 51^\circ$

These are graphically shown in Fig. 99.

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\* Etude sur la détermination des feldpaths, 1894.

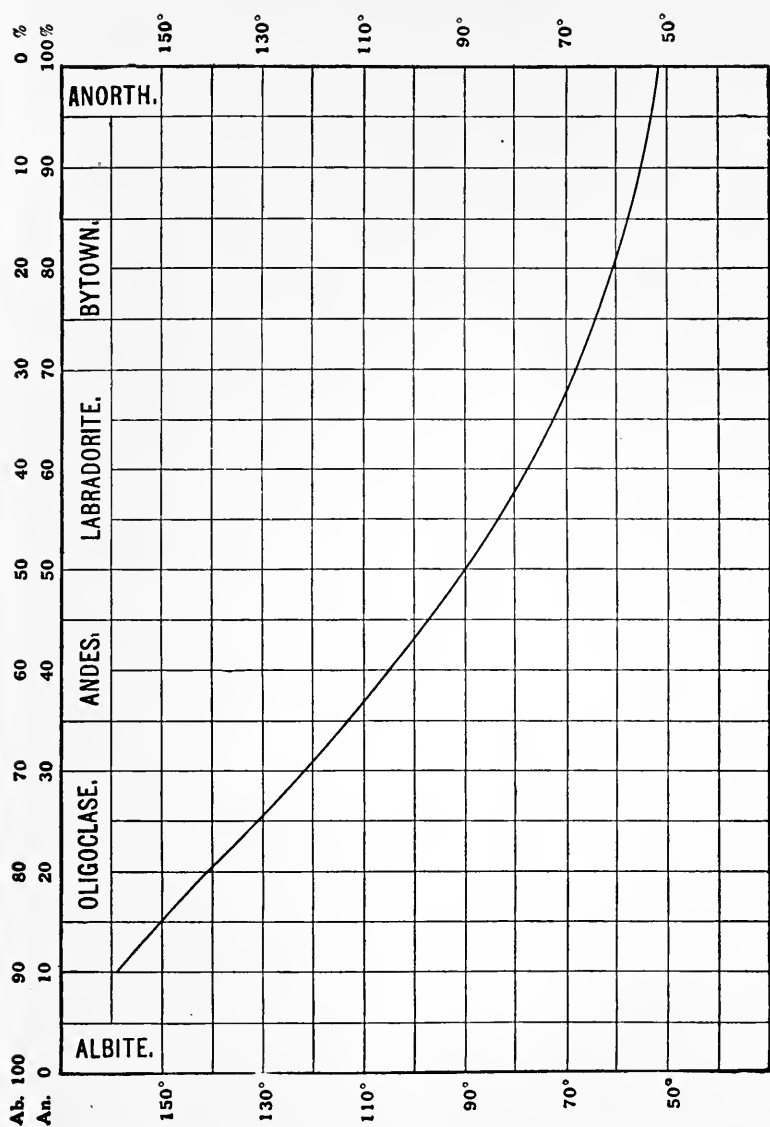


FIG. 99.—Curve showing the angle  $\omega$  between the two extinctions in Carlsbad twins of lime-soda feldspars in (010) sections.

9. *By the extinction angle on sections at right angles to both (001) and (010).* (Method used by Becker\* and Becke.†) These sections are easily recognizable in microlites and in phenocrysts of eruptive rocks by their nearly quadratic sections, and in the granular rocks by zonal growths with quadratic outlines. Sections at right angles to both (001) and (010) have the division lines between the albite twinning lamellæ and the (001) cleavage lines extending at right angles to the section; consequently, when the tube of the microscope is slightly raised or lowered, there will be no lateral displacement of these lines.

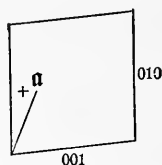


FIG. 100.

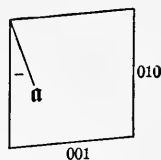


FIG. 101.

FIGS. 100-101.—Cross-sections at right angles to both (001) and (010) showing (+) and (−) character of extinction in plagioclase feldspars.

When twinning and cleavage lines are wanting in microlites, one needs but remember that the extinction angle from (010) to  $\alpha$  is always less than  $45^\circ$ , consequently it is the smaller extinction angle. The small cross-sections, Figs. 100 and 101, show the directions of (+) and (−) extinction; the angles are shown in Fig. 102.

If the cross-section does not happen to be exactly at right angles to (001) and (010), it does not greatly matter, for the variation on tilting the section is small near this position. This method is good, because the increase in the extinction angle from albite to anorthite is rapid and uniform.

\* U. S. Geological Survey. 18th Annual Report, part III, 1898, p. 34.

† Tschermak's Mineralogische und petrographische Mittheilungen. Vol. 18, 1900, p. 556.

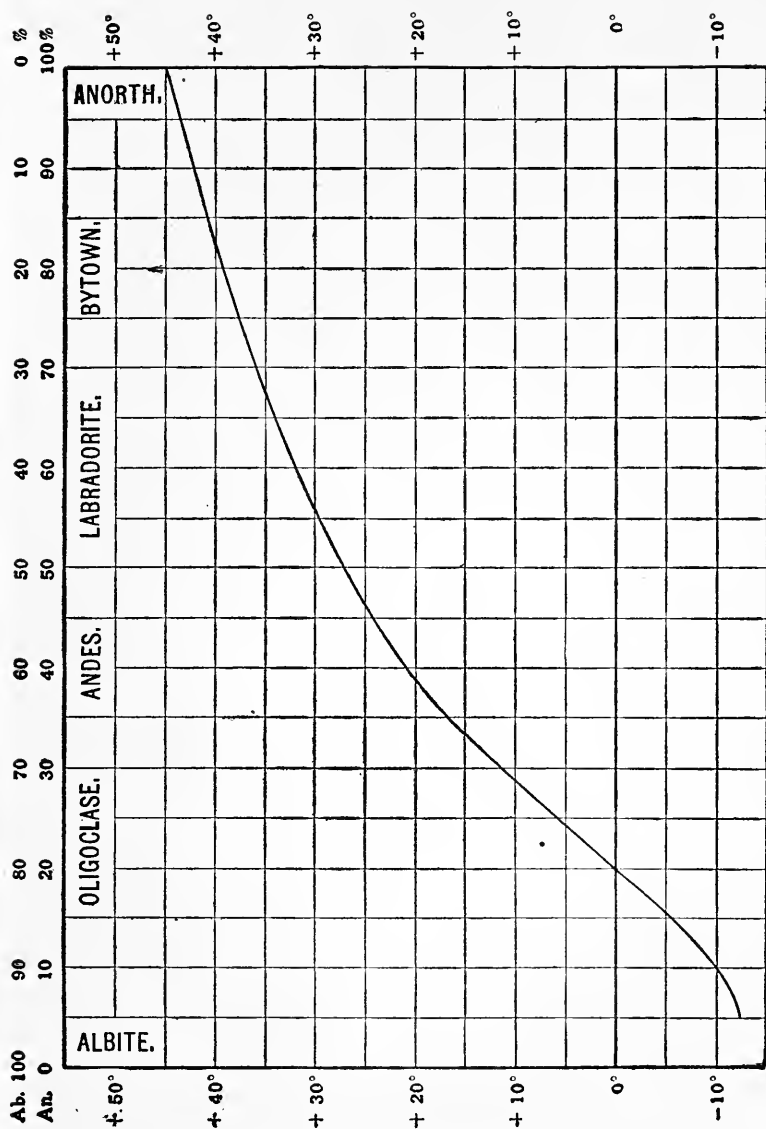


FIG. 102.—Extinction angles from  $a$  to the (010) cleavage of lime-soda feldspars in sections cut at right angles to both (010) and (001). (Becker and Becke's method.)

10. *By the extinction angle on sections at right angles to either bisectrix.* (Fouqué.\*)

Sections cut at right angles to the bisectrices may be easily recognized by the fact that they show, in parallel light, an interference color intermediate between the maximum and minimum tints. In convergent light the interference figure will show as a cross in the center of the field, when the principal sections of the slide and nicols are parallel. This cross will open into two symmetrically located hyperbolæ, when the section is rotated into the diagonal position. The section must next be tested by means of a gypsum plate, to see whether it is at right angles to the *a* or the *c* axis. If the line connecting the hyperbolæ has less ease of vibration than that at right angles to it, that is, if the *c* direction connects the eyes while the *b* direction is at right angles to it and in the plane of the section, the slide is one which is cut at right angles to *a* and *vice versa*.

In sections at right angles to *a* the extinction angle is measured from the twinning lines (Fig. 103, solid line).

In sections at right angles to *c*, in the basic feldspars, the extinction angle is measured from the trace of the twinning lines or of the (010) cleavage. (Fig. 103, dotted line.) In the acid feldspars the section at right angles to *c* is very near the (010) face, and therefore shows neither twinning lamellæ nor (010) cleavage; the extinction is measured from the (001) cleavage. (Fig. 103, broken line.)

The following values are given by Fouqué. Sections at right angles to *a* give good values as high as  $Ab_1An_1$ , and are of use when one can determine the positive or negative direction of extinction. The values in sections at right angles to *c* are good in the basic feldspars.

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\* Contribution à l'étude des feldspaths des roches volcanique, Bulletin de la Société minéralogique de France, Vol. XVII, 1894, p. 306.

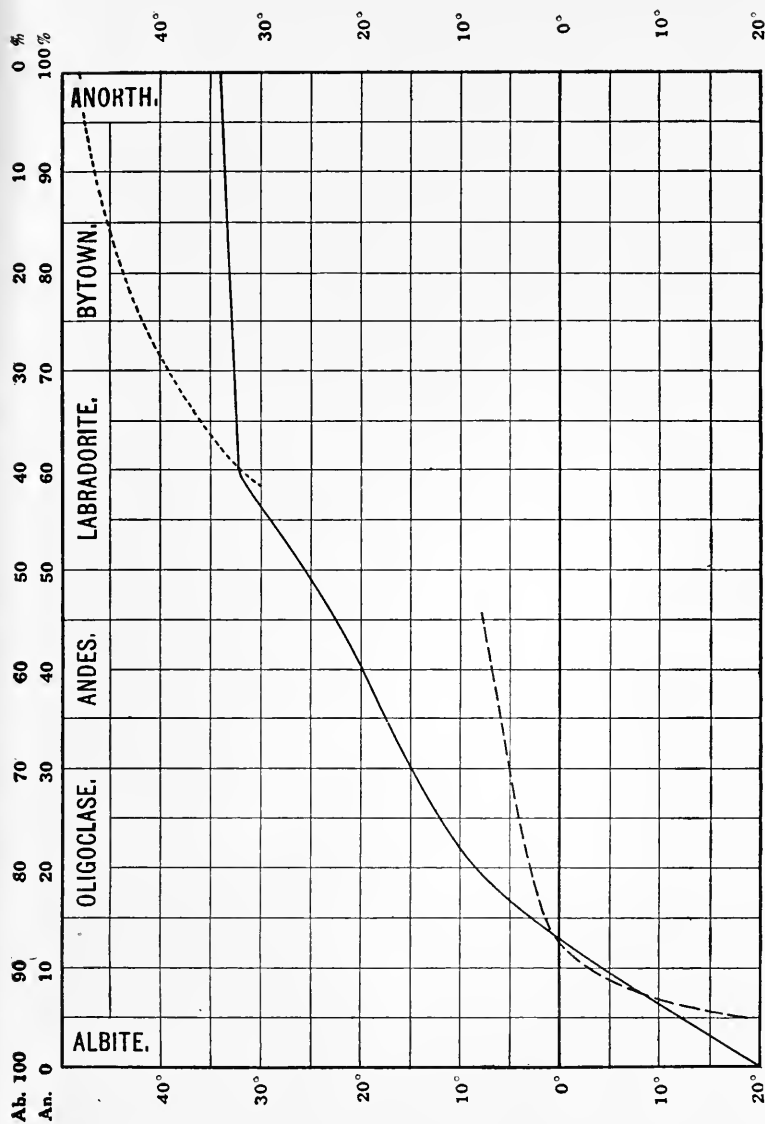


FIG. 103.—Extinction angles in sections of lime-soda feldspars cut at right angles to either bisectrix. Solid line: Extinction angles from the twinning lamellae in sections at right angles to  $\alpha$ . Broken line: Extinction angles measured from the (001) cleavage in sections at right angles to  $\epsilon$ . Dotted line: Extinction angles measured from the trace of (010) in section at right angles to  $\epsilon'$ . (After the diagram constructed by Rosenbusch from the values given by Fouqué.)

		Sections $\perp$ to (a).	$\perp$ to (c).	
Albite,	Ab <sub>95</sub> An <sub>5</sub>	-13°	-19°	Measured from the (010) cleavage
Oligoclase-albite,	Ab <sub>90</sub> An <sub>10</sub>	- 5°	- 3°	
Oligoclase,	Ab <sub>75</sub> An <sub>25</sub> ,	+12°	+ 4°	
Andesine,	Ab <sub>55</sub> An <sub>45</sub> ,	+22.5°	+ 7.5°	
Labradorite,	Ab <sub>40</sub> An <sub>60</sub> ,	+32°	+32°	
Bytownite,	Ab <sub>25</sub> An <sub>75</sub>	+33°	+42°	
Anorthite,	An,	+34°	+48°	

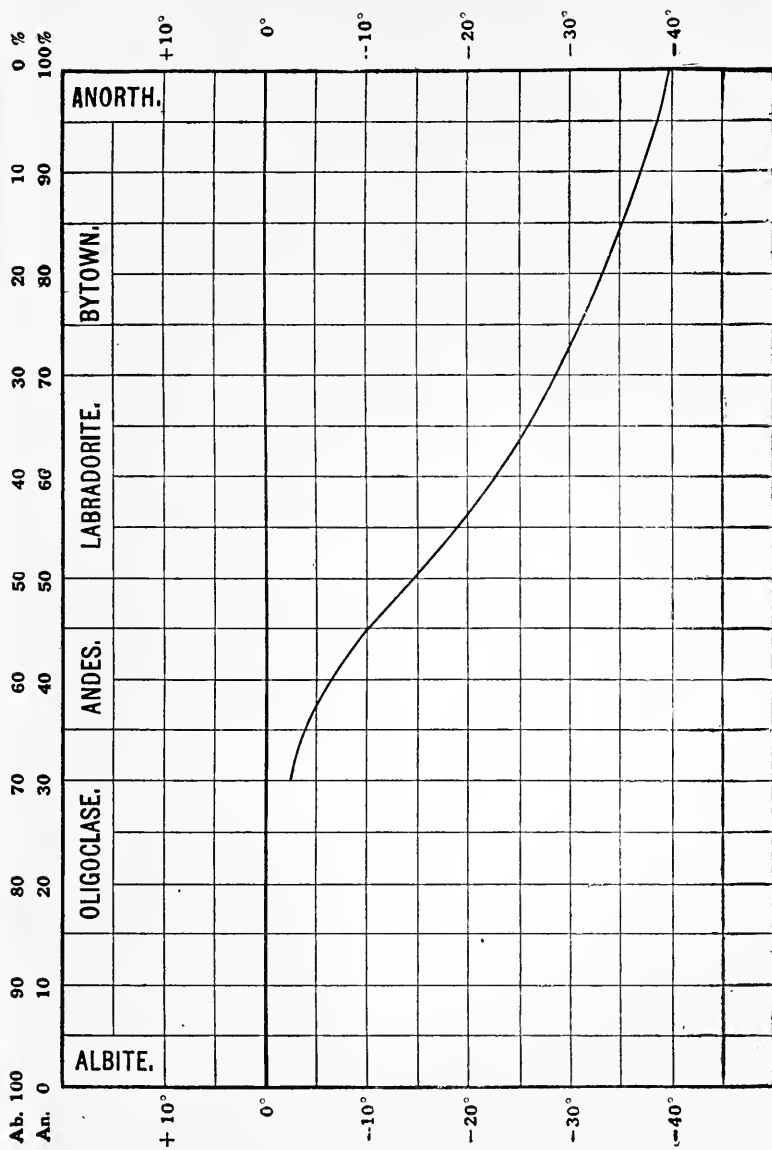
11. *By the extinction angle on sections at right angles to the optic normal (b).* (Fedorow.)

The interference colors between crossed nicols in sections at right angles to the optic normal are the highest of any in that mineral. In thin sections of feldspar as usually cut for microscopical use, the colors seldom exceed yellow of the first order, and the highest color may be difficult of determination. A very convenient way of making the tints more distinct is to turn the nicols into parallel position. The tints are given on pp. 10 and 20. Extinctions in the acid feldspars from albite to andesine, in sections at right angles to an optic normal, vary only from +2° to -2°; but in the feldspars from andesine to anorthite they change rapidly from -6° to -39° (Fig. 104).

12. *By the extinction angle on sections from the (001), (010) zone.* (Extinction angles of microlites.) In sections from this zone the (001) and (010) cleavages are parallel. Spherulite rays and the microlites of the effusive rocks are bounded by these cleavages. In these sections the extinction angle increases from 0° to a different maximum in each feldspar. Basic oligoclase has the lowest maximum, and anorthite has the highest. Since it is impossible to obtain the positive or negative character of the extinction in microlites, albite and andesine cannot be separated; above 20° the method is good. (Fig. 105.)

Albite and andesine may be separated by the indices of refraction, and their extinction angles may then be used.



Fig. 101.—Extinction angles of lime-soda feldspars in sections cut at right angles to  $\bar{b}$ . (Fedorow's method.)

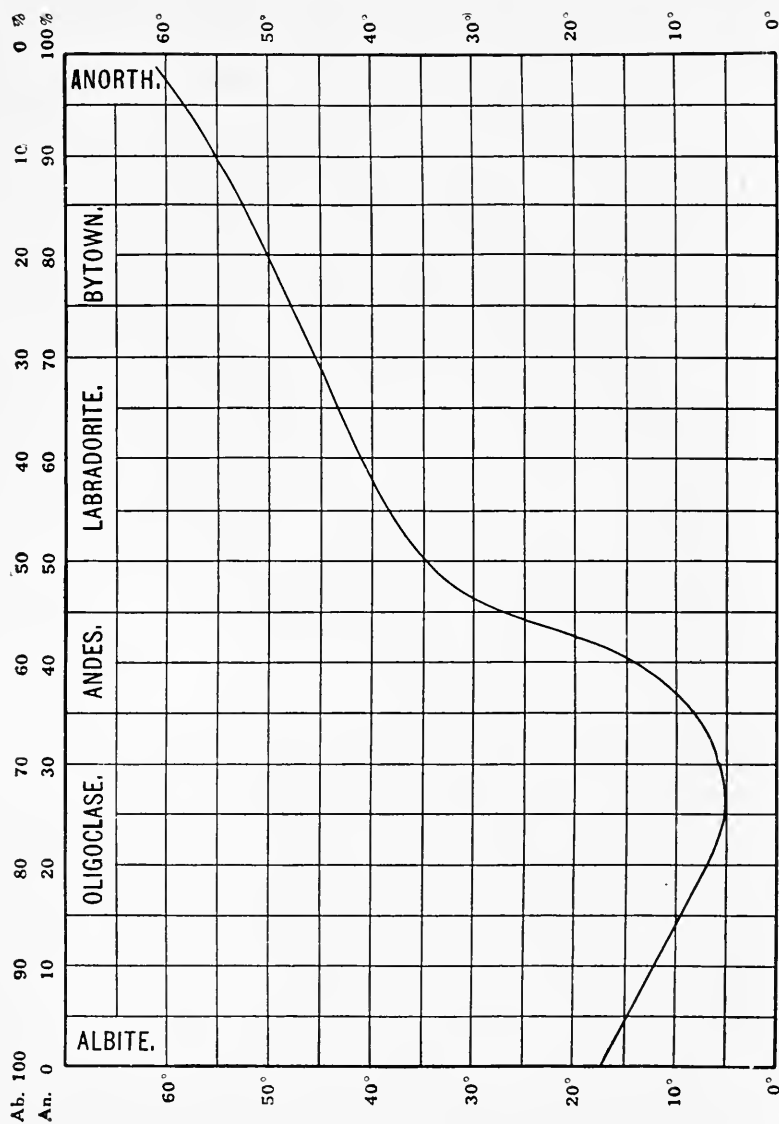


FIG. 105.—Extinction angles in microlites of the lime-soda feldspars. Zone (010):(001). (After the diagram constructed by Rosenbusch. The right end should rise somewhat less steeply; the value assumed for the anorthite from Vesuvius, which was used in constructing the curve, being  $Ab_{90}An_{10}$ .)

13. *By the extinction angles on sections from the zone at right angles to (010) or the symmetrical zone.* (Statistical method of Michel-Lévy.\*) Sections in this zone may be recognized as follows: (1) the albite twinning lamellæ are separated by very sharp lines, which, since they do not overlap, are not laterally displaced upon raising or lowering the tube of the microscope; (2) the extinction angle from the twinning line of the albite twins of one system is the same to the right as it is for the other to the left; and (3) if a section at right angles or very nearly at right angles to the twinning plane is turned until the twinning lines make an angle of  $45^\circ$  with the principal sections of the crossed nicols, the two systems of twins and the narrow strips where they overlap will become of uniform color, and the section will have the appearance of a simple crystal. The latter is the quickest and most sensitive method of finding sections in this zone.

Each section in the zone at right angles to (010) has equal extinction angles, varying from  $0^\circ$  to a maximum, on either side of the twinning line, but only one section gives the maximum extinction, which is different in each species of feldspar, as is also the position of this plane giving maximum extinction. (Fig. 106.)

This method is one of the most valuable for the determination of the feldspars, although confusion might arise if two species occur in the same rock, or if there are but few feldspar sections in the slide and none of them gives the maximum extinction. Another confusion arises in the positive and negative character of the extinction angles of albite and oligoclase-albite, on the one hand, and andesine on the other.

The number of sections occurring in a slide which give good results by this method is greatly increased by the fact that sections varying  $10^\circ$  or more from the true position may be used. In such sections the extinction angles on either side of the twinning lamellæ will not be the same, but half of the sum of the

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\* Annales des mines, 1877, pp. 392-471.

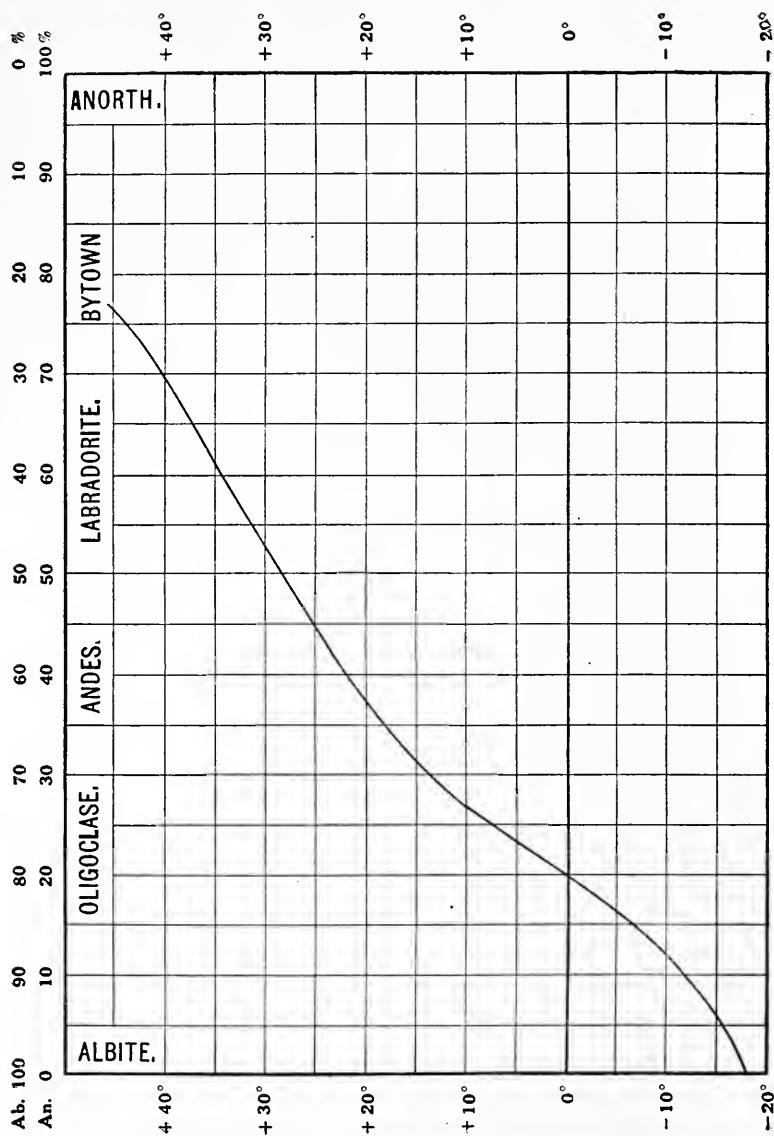


Fig. 106.—Maximum extinction angles in the lime-soda feldspars in the zone at right angles to (010), measured from the albite twinning lamellae. ("Statistical method" of Michel-Lévy.)

two angles very nearly coincides with the true values found in the zone.

The following values are given by Rosenbusch for the maximum extinction angles:

Ab <sub>95</sub> An <sub>5</sub>	-15.2°
Ab <sub>86</sub> An <sub>14</sub>	- 7.7°
Ab <sub>75</sub> An <sub>25</sub>	+ 6.8°
Ab <sub>63</sub> An <sub>37</sub>	+19.3°
Ab <sub>50</sub> An <sub>50</sub>	+28°
Ab <sub>25</sub> An <sub>75</sub>	+43.7°
Ab <sub>0</sub> An <sub>100</sub>	90°

14. *By the extinction angles on sections from the zone at right angles to (010), when the albite twinning is combined with Carlsbad twinning.* (Michel-Lévy.) If the albite twins of the preceding section are combined with Carlsbad twins, the difference in extinction between the two systems will determine the feldspar. When these twins are in combination, the sections in the zone at right angles to (010) may be recognized by the fact that in the 45° position the albite twinning disappears and the crystal appears as a simple Carlsbad twin. If one turns the stage of the microscope so that the traces of the twinning planes are parallel to the cross-hairs of the microscope, the albite and Carlsbad twinning will both disappear and the feldspar be equally illuminated, except for the fact that the narrow lines, where the albite lamellæ overlap, will appear as fine black lines.

Michel-Lévy\* has recently published very useful diagrams for the determination of plagioclase feldspars in this zone, with these twins combined. By observing the extinction angles, without considering the sign, the pole of the section chosen and the percentage of anorthite in the plagioclase may be determined from the diagram (Fig. 107).

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\* Étude sur la détermination des feldspaths, Troisième fascicule, 1904.

A section is chosen which gives approximately the maximum extinction in or very near the zone of symmetry, that is, one in which the position of greatest illumination, as explained above, is at  $45^\circ$ . (As in the preceding case, sections inclined as much as  $10^\circ$  from the perpendicular to (010) may be used.) The different values of symmetrical extinction of the two individuals of the Carlsbad twin are taken, and of these the smaller is found in the column at the left (Fig. 107) and the larger upon the curves. The vertical line at the intersection of the two gives the percentage of the anorthite molecule. The broken lines indicate the angles which the sections make with the (100) face. The size of this angle is indicated by the figures which are not followed by the degree ( $^\circ$ ) mark in the diagram.

## PART III.

### EXPLANATION OF THE TABLES.

THE method of using the following tables needs but little explanation. A brief résumé of methods and a few cautions may be helpful.

**The mineral is**

**Opaque.** Observations are made with the analyzer out, color determined by incident light.

**Isotropic or anisotropic.** Observations made in polarized light, nicols crossed. With slightly isotropic minerals it may be necessary to make use of the gypsum plate (p. 12). Basal sections of uniaxial minerals are isotropic but give an interference figure.

**Extinction parallel or inclined.** Angles are measured from the cross-hairs of the microscope. For very small angles a Bertrand ocular (p. 13) may be used. In cases where the extinction angle of a mineral is less than  $5^{\circ}$ , it will be found under minerals having parallel extinction as well as under minerals having inclined extinction, thus allowing for slight errors in observation.

**Color.** Minerals nearly colorless, or which occur both colorless and colored, are given under both heads.

**Pleochroism.** Observed in plane polarized light.

**Index greater or less than Canada balsam.** Observed by Becke method (p. 14).

**Maximum birefringence greater or less than quartz.** In sections of normal thickness this may be determined at once

by the eye, using polarized light. In sections of unknown thickness containing quartz or any other known mineral, it may be determined by the quartz wedge, mica wedge, or compensator (pp. 18-21).

**Uniaxial or biaxial character.** Determined by obtaining interference figures (pp. 24-30).

**Optical character.** Determined with some accessory (pp. 35-43).

**Value of birefringence.** Obtained by comparison with known minerals by the use of some accessory (pp. 18-21). Amann's birefractometer and the Babinet compensator are excellent (p. 21).

**Index of refraction.** Determined by comparing (Becke method) the unknown mineral with one that is known or with the Canada balsam in contact, or by any of the methods given on pages 14 and 15. Care should be exercised in estimating the value of the index of refraction of a mineral, especially if it has medium or high relief, when there is no known mineral in the rock section with which to compare it. A colorless mineral with medium relief appears rougher than a colored one with high relief.

The spacing of the indices and the double refraction upon the diagrams is uniform until the very high figures are reached. Since few minerals occur here, and the difference in relief and birefringence is hard to estimate, this is of no importance. The length of the line under each mineral gives the range of its indices of refraction; the position of the line, its maximum birefringence.

After narrowing down the characteristics of an unknown mineral, one may find at that point, upon the plate, a group of several from which it can readily be separated by referring to the descriptive tables opposite, which are arranged in the same order as are the minerals upon the plates. When some of the properties of a mineral as, for example, its uniaxial or biaxial, or positive or negative character are indeterminable, it may be necessary to follow out two divisions; but even when it becomes necessary to look under both classes the known



properties will reduce the possible minerals to a small number.

Throughout the tables, the following form has been observed:

Name.—*Chemical composition*, *H* = Hardness, *G* = Specific gravity.

*System*. *Optical character of mineral* (+ or -).

*Cleavage*. *Cleavage angle*.

*Habit*. Common form of occurrence, twinning, etc.

*Elongation*. The principal zone or plane. *Optical character of elongation* (+ or -).

*Optical orientation*. Giving the extinction angles, etc.

*Color*.

*Pleochroism*.

*Indices of refraction*.

*Birefringence*.

*Dispersion*.

*Axial angle*.

*Chemical and physical properties*.

**Other minerals which are similar** and characteristics by which they may be distinguished.



## NOTICE.

Since it is impossible to fold the signatures of every book exactly alike, it is suggested that the student first cut all of the descriptive pages on the lines indicated, and then cut the guide pages as follows, paying no attention to the positions of the printed lines:

A. The upper third of page 99, the upper two-thirds of page 105, and the whole of page 139 form the widest guides and should be of the same width. They form the first series of guides.

B. The upper halves of pages 107 and 141, and the whole of pages 121 and 371 should be of the same width and form the second series of guides. They are one space narrower than the "A" guides.

C. The upper halves of pages 109, 123, 143 and 373, and the whole of pages 117, 129, 259 and 437 form the third series of guides and are one space narrower than "B."

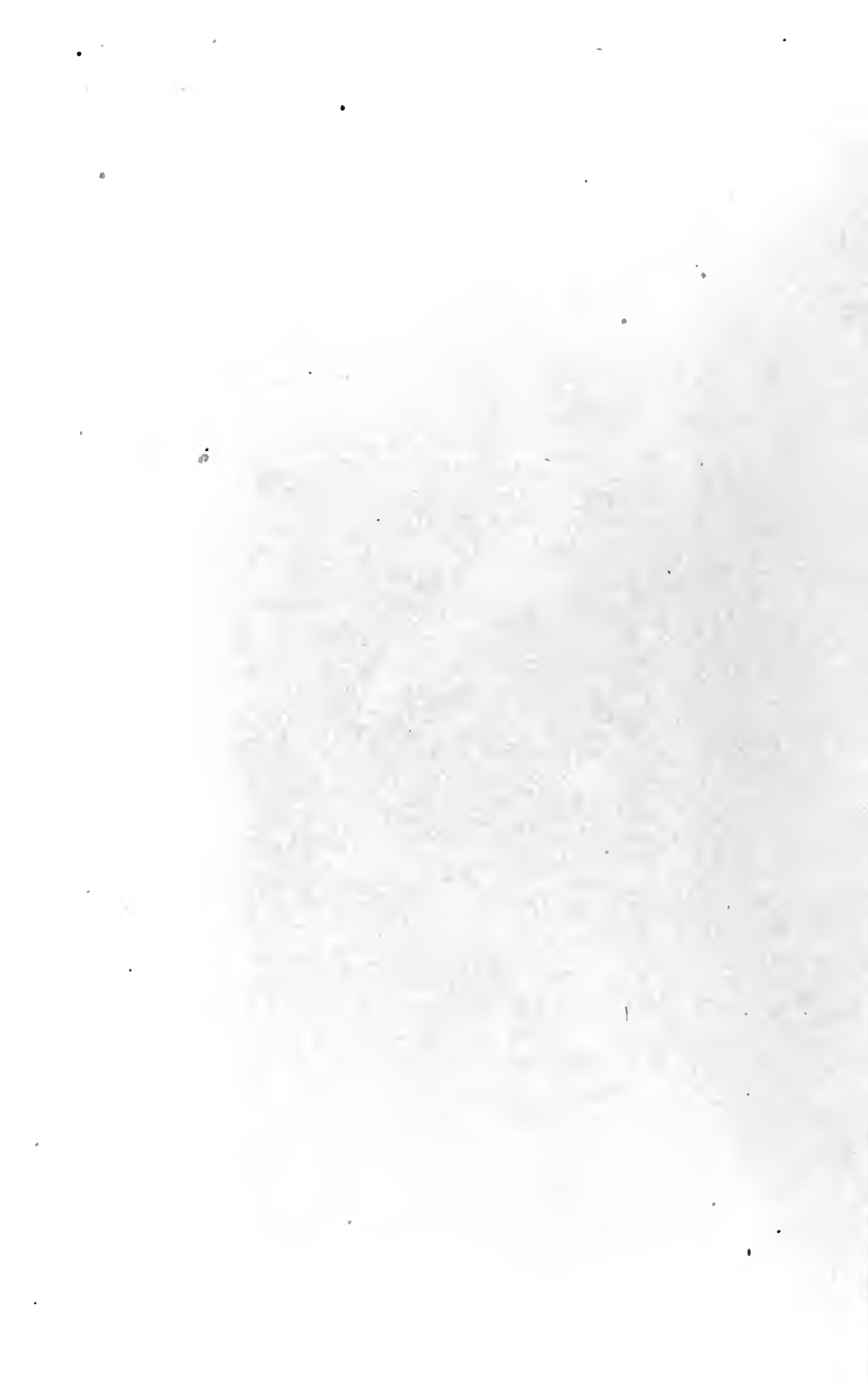
D. The upper halves of pages 145, 261, 375 and 439, and the whole of pages 181, 315, 399 and 467 form the fourth series of guides and are one space narrower than "C."

E. The upper halves of pages 147, 183, 263, 317, 377, 401, 441 and 469, and the whole of pages 165, 209, 281, 333, 391, 411, 447 and 479 form the fifth series of guides and are one space narrower than "D."

F. The upper halves of pages 149, 167, 185, 211, 265, 283, 319 and 335, and the whole of pages 157, 173, 197, 227, 273, 293, 325 and 345 form the sixth series of guides and are one space narrower than "E."

Pages 259 and 281 should not be indented, but should have straight edges and be of the width indicated at the top. The guide words should be transferred to the lower halves of these pages.

After having cut the guide pages according to these directions, the index slips on the accompanying sheets should be separated on the lines, and pasted in their proper positions on the stubs.



The mineral is opaque.

The mineral is opaque.

<b>Yellow</b> by incident light. . . . .	<b>Pyrite.</b>
	Pyrrhotite.
<b>Black</b> by incident light. . . . .	<b>Magnetite.</b>
	Graphite.
	<b>Ilmenite.</b>
Thin edges <b>transparent:</b>	
<b>Red</b> . . . . .	<b>Hematite.</b>
<b>Brown</b> . . . . .	<b>Chromite.</b>
	Picotite.

**Pyrite.**— $\text{FeS}_2$ ,  $\text{H} = 6.0\text{--}6.5$ ,  $\text{G} = 4.9\text{--}5.21$ ,  
Isometric.

Cleavage: Not seen in thin sections.

Habit: Cubes, octahedrons, and irregular grains.

By incident light: Yellowish with metallic luster.

Non-magnetic; insoluble in HCl.

Magnetite is black by incident light, and, when pulverized, is attracted by the magnet.

**Pyrrhotite.**— $\text{Fe}_n\text{S}_{n+1}$ ,  $\text{H} = 3.5\text{--}4.5$ ,  $\text{G} = 4.58\text{--}4.64$ .  
Hexagonal.

Prismatic cleavage; not seen microscopically.

Habit: Irregular grains.

By incident light: Bronze-yellow with metallic luster.

Is somewhat attracted by the magnet when pulverized. Soluble in HCl.

Pyrite is not attracted by the magnet and is insoluble in HCl.

**Magnetite.**— $\text{Fe}_3\text{O}_4$ ,  $\text{H} = 5.5\text{--}6.0$ ,  $\text{G} = 4.9\text{--}5.2$ .  
Isometric.

Cleavage: (111), rarely seen under the microscope.

Habit: Octahedrons, cubes, irregular grains, dust.

By incident light: Metallic, bluish black.

Attracted by magnet; soluble, even in thin sections, in HCl.

Pyrite, ilmenite, chromite, and graphite are not attracted by the magnet.

Pyrite, chromite, and graphite are insoluble in acids.

Ilmenite is soluble with difficulty in acids and gives reaction for Ti.

**Graphite.**— $\text{C}_n$ ,  $\text{H} = 1.0\text{--}2.0$ ,  $\text{G} = 2.1\text{--}2.3$ .  
Hexagonal.

Cleavage: (0001), perfect.

Habit: Hexagonal to rounded plates; scale-like and rod-like aggregates.

By incident light: Metallic luster to dull black or steel-gray.

Slightly consumed in BB. Insoluble in acids. Black streak.

Molybdenite is not combustible, but gives off fumes of  $\text{SO}_2$  and has a green streak.

**Ilmenite.**— $\text{FeTiO}_3$ ,  $\text{H} = 5.0\text{--}6.0$ ,  $\text{G} = 4.5\text{--}5.0$ .  
Hexagonal.

Cleavage: Not distinct.

Habit: Tabular, thin plates, scales.

Elongation: (0001), lath-shaped.

Madder to clove brown on thin edges. Submetallic luster.

$\omega$  = high,  $\epsilon$  = high.

$\omega - \epsilon$  = high.





Slowly soluble in hot HCl; with tin the solution becomes violet. Very slightly or not attracted by the magnet. Characteristic alteration to leucoxene.

**Magnetite** is readily soluble in acids and is magnetic.

**Hematite** is red to yellow on thin edges.

**Titaniferous magnetite**; separation may be difficult. Different crystalline system.

**Hematite.**— $\text{Fe}_2\text{O}_3$ , H = 5.5–6.5, G = 4.9–5.3.

Hexagonal. (–).

Cleavage: Not distinct.

Habit: Tabular, thin plates, scales.

Elongation: (0001), lath-shaped. (+).

Red, yellowish, yellowish gray.

Pleochroism: O = brownish red, E = light yellowish red.

$\omega = 3.22$ ,  $\epsilon = 2.94$ .

$\omega - \epsilon = 0.28$ .

Becomes magnetic in the reducing flame. Very slowly soluble in acids. Not attracted by magnet. Streak, red.

**Magnetite** is magnetic and readily soluble in HCl.

**Limonite** and earthy hematite may be confused.

**Rutile** is optically (+). Habit is different.

**Chromite.**— $\text{FeCr}_2\text{O}_4$ , H = 5.5, G = 4.32–4.57.

Isometric.

No cleavage.

Habit: Octahedrons, grains.

Incident light: Brownish black; thin edges same.

Insoluble in acids. Cr reaction.

**Magnetite** is magnetic and soluble in HCl.

**Ilmenite** gives Ti reaction.

**Picotite.**— $(\text{Mg}, \text{Fe})\text{O} \cdot (\text{Al}, \text{Cr}, \text{Fe})_2\text{O}_3$ , H = 7.5–8.0, G = 4.80

Isometric.

Cleavage: Imperfect.

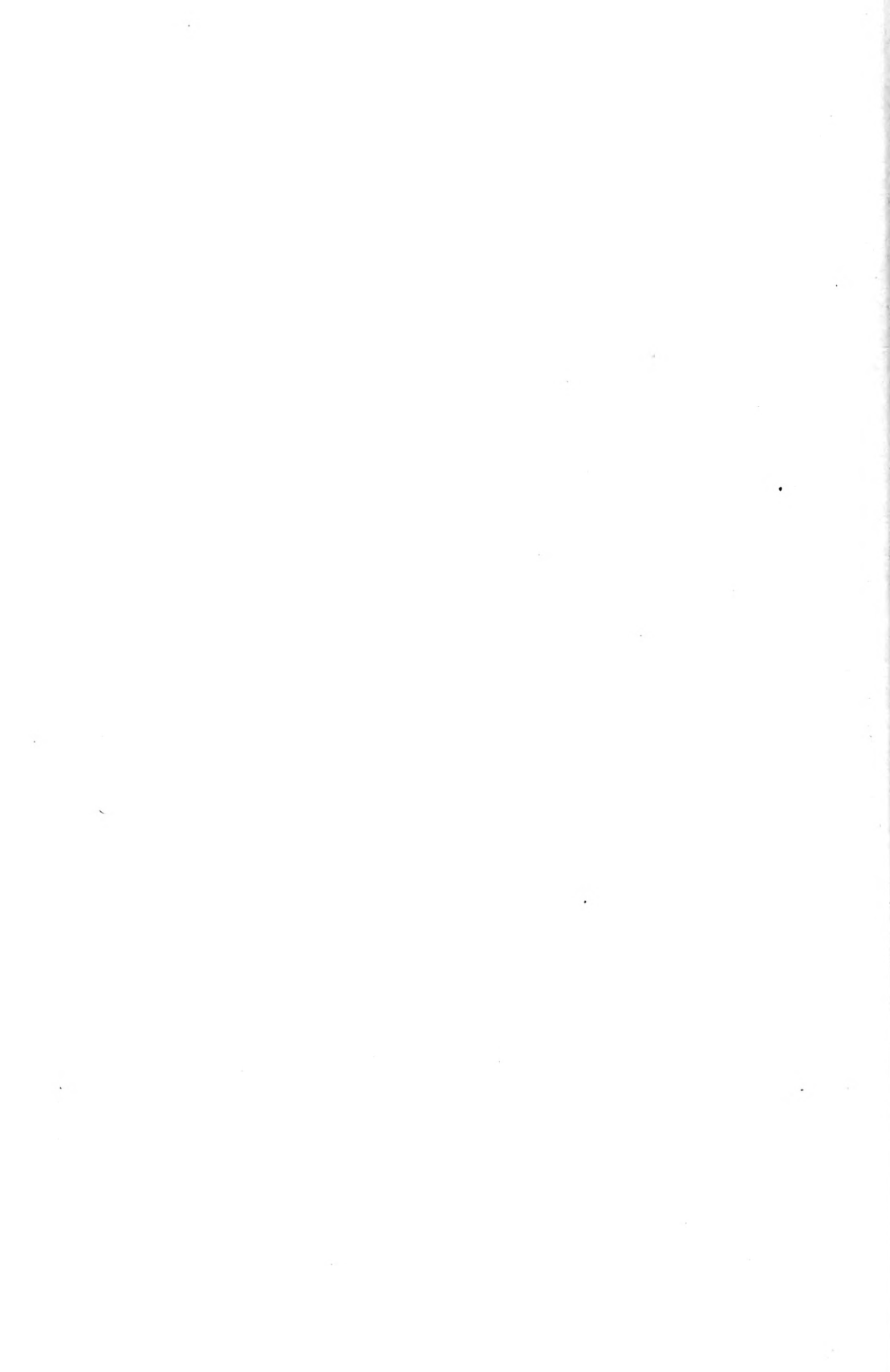
Habit: Grains, rarely octahedrons.

Yellow or brown to greenish brown on thin edges.

Index about 1.7.

Occurs as inclusions in olivine, rarely individuals in basalt, grains in lherzolite, etc.

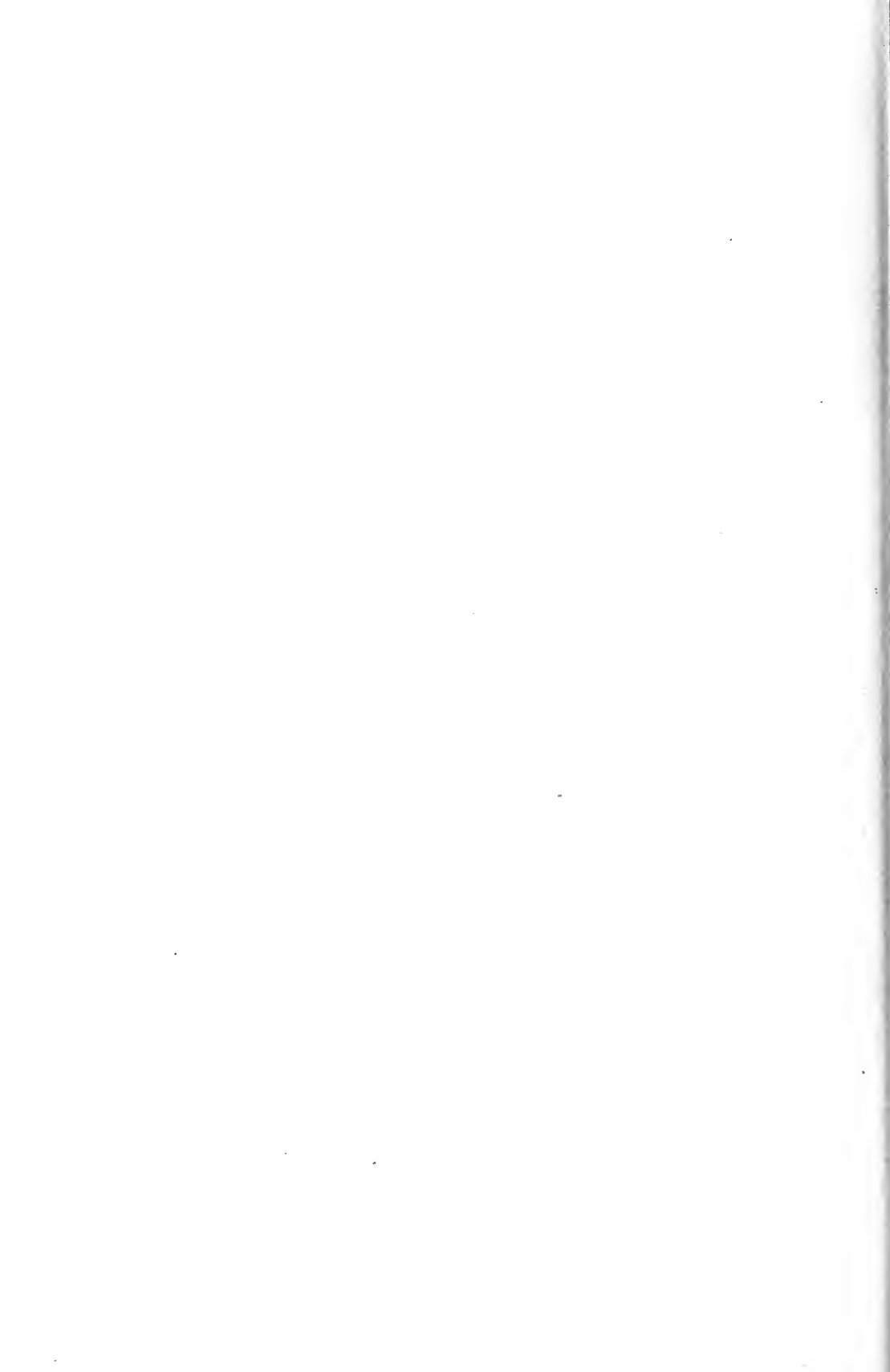
**Chromite** is distinguished by hardness specific gravity and chemically.



The mineral is **isotropic**.

ISOTROPIC.

*Cut on line.*



The mineral is isotropic.

Colorless.

COLORLESS.

*Cut on line.*



The mineral is isotropic.

Colorless.

Index of refraction is less than  
that of Canada balsam.

INDEX < CANADA BALSAM.

*Cut on line.*

The mineral is isotropic, colorless, index of refraction is less than that of Canada balsam.

(Arranged according to mean indices of refraction.)

The mineral forms crystals. . . .	<b>Fluorite.</b> . . . . .	$n = 1.433$
	<b>Sodalite.</b> . . . . .	1.483
	<b>Noselite.</b> . . . . .	1.490
	<b>Häüynite.</b> . . . . .	1.503
	<b>Leucite.</b> . . . . .	1.508
The mineral fills cavities or is		
amorphous. . . . .	<b>Opal.</b> . . . . .	$n = 1.443$
	<b>Glass.</b> . . . . .	1.490
Cavity filling or attached crystals. . . . .		
	<b>Analcite.</b> . . . . .	$n = 1.488$



**Fluorite.**—  $\text{CaF}_2$ ,  $H = 4.0$ ,  $G = 3.18-3.20$ .

Isometric.

Cleavage: Perfect (111).

Habit: Seldom shows crystal form; generally cavity and inter-space filling, or irregular or drop-like grains.

Colorless to violet or purple. Color often irregularly or zonally distributed.

Index:  $n = 1.4332-1.4340$ .

With  $\text{H}_2\text{SO}_4$  gives off hydrofluoric acid which will etch glass; very slightly affected by other acids.

Opal and sodalite groups have higher indices and are often slightly anisotropic.

Opal has no cleavage.

Sodalite group is attacked by weak acids and has (110) cleavage.

Other colorless minerals usually have lower specific gravities and higher indices.

**Sodalite** —  $(\text{SiO}_4)_3\text{Al}_2 \cdot \text{AlCl} \cdot \text{Na}_4$ ,  $H = 5.5$ ,  $G = 2.28-2.34$ .

Isometric.

Cleavage: Sometimes fair (110).

Habit: Cloudy quadratic, hexagonal, or rounded grains, often distorted.

Colorless, bluish, greenish, light pink, red, yellowish.

Index:  $n_a = 1.4827-1.486$ .

Anomalous double refraction is rare.

Gelatinizes with  $\text{HCl}$ ; crystals of  $\text{NaCl}$  form on drying. Gelatinizes even in thin sections with acetic acid.

Isotropic grains (except glass, fluorite, leucite, and analcite) have higher indices.

Glass has no cleavage and no crystal form.

Leucite, fluorite, and analcite have different cleavage, gelatinize with greater difficulty, have twinning and different chemical reactions.

Häüynite, noselite, and lazurite are separated by chemical tests, cleavage, and crystal form.

**Noselite.**—  $(\text{SiO}_4)_3\text{Al}_2 \cdot \text{AlSO}_4\text{Na} \cdot \text{Na}_4$ ,  $H = 5.5$ ,  $G = 2.27-2.50$ .

Isometric.

Cleavage: Usually shows right-angled cleavage in cross-sections parallel to (100) and (110). Sections parallel to (111) show three series of lines cutting each other at  $60^\circ$ .

Habit: Usually occurs as crystals, crystal fragments, or rounded grains.

Colorless, blue, gray, brownish, red, yellow, and green. The color is often irregularly distributed or zonal.

Index:  $n_a = 1.495$ .



Often has opaque borders, and is often altered. Gelatinizes easily with HCl, and few gypsum crystals and many NaCl crystals form. Sometimes shows optical anomalies.

**Haüynite** gives many gypsum crystals in drying gelatine from HCl.

**Sodalite** has less perfect cleavage, and seldom has borders.

**Haüynite.**— $(\text{SiO}_4)_3\text{Al}_2 \cdot \text{AlSO}_4\text{Na} \cdot \text{CaNa}_2$ ,  $H = 5.5$ ,  $G = 2.27-2.50$ .  
Isometric.

Cleavage: Cross-sections parallel to (100) and (110) show two systems at right angles.

Habit: Usually occurs in crystals (110), crystal fragments, or rounded grains.

Colorless, blue, gray, brownish, red, yellow, and green. Color often irregularly distributed or zonal.

Index:  $n_{na} = 1.496-1.504$ .

Sometimes shows optical anomalies either about inclusions or as a dark cross. Haüynite usually contains inclusions at the center or around periphery. It is often altered. Gelatinizes easily with HCl, and gypsum crystals result from the drying gelatine.

**Noselite** gives few gypsum crystals.

**Sodalite** has less perfect cleavage, and seldom has borders.

**Leucite.**— $\text{KAlSi}_3\text{O}_8$ ,  $H = 5.5-6.0$ ,  $G = 2.45-2.5$ .  
Isometric.

Cleavage: Not noticeable; irregular cracks.

Habit: Six- or eight-sided to rounded grains. Very often contains inclusions in regular zones.

Colorless to gray.

$\omega = 1.508$ ,  $\epsilon = 1.509$ .

$\epsilon - \omega = .001$  and less. Optical anomalies; shows polysynthetic twinning.

HCl attacks leucite slightly in thin sections, but the powdered mineral is dissolved with a separation of silica.

**All minerals but analcite** differ from leucite in having higher indices and higher double refraction. The twinning and crystal form of leucite also distinguishes it.

**Analcite and sodalite groups** may be confused with isotropic leucite. Either may be distinguished by the greater resistance of leucite to HCl and by its micro-chemical reactions, giving isometric potassium fluosilicate crystals, while analcite gives hexagonal sodium fluosilicate crystals.

**Opal.**— $\text{SiO}_2 + \text{aq.}$ ,  $H = 5.5-6.5$ ,  $G = 1.9-2.3$ .  
Amorphous.  
Cleavage: Wanting.



Habit: Irregular grains, vein filling, druses; pseudomorphs after feldspar, augite, or other silicates.

Transparent, colorless.

Index: Low, varying with aq. contents. Mean: 1.36-1.458.

Birefringence: Low. Anomalous double refraction in irregular patches and spots is not uncommon.

**Analcite.**— $\text{NaAlSi}_2\text{O}_6 + \text{H}_2\text{O}$ ,       $H = 5.5$ ,       $G = 2.15-2.18$ .  
isometric. (+).

Cleavage: Medium (100).

Habit: Druses or cavity filling, cloudy grains (211); pseudomorphs after leucite, nephelite, or sodalite.

Colorless, white.

Index:  $n = 1.486-1.488$ .

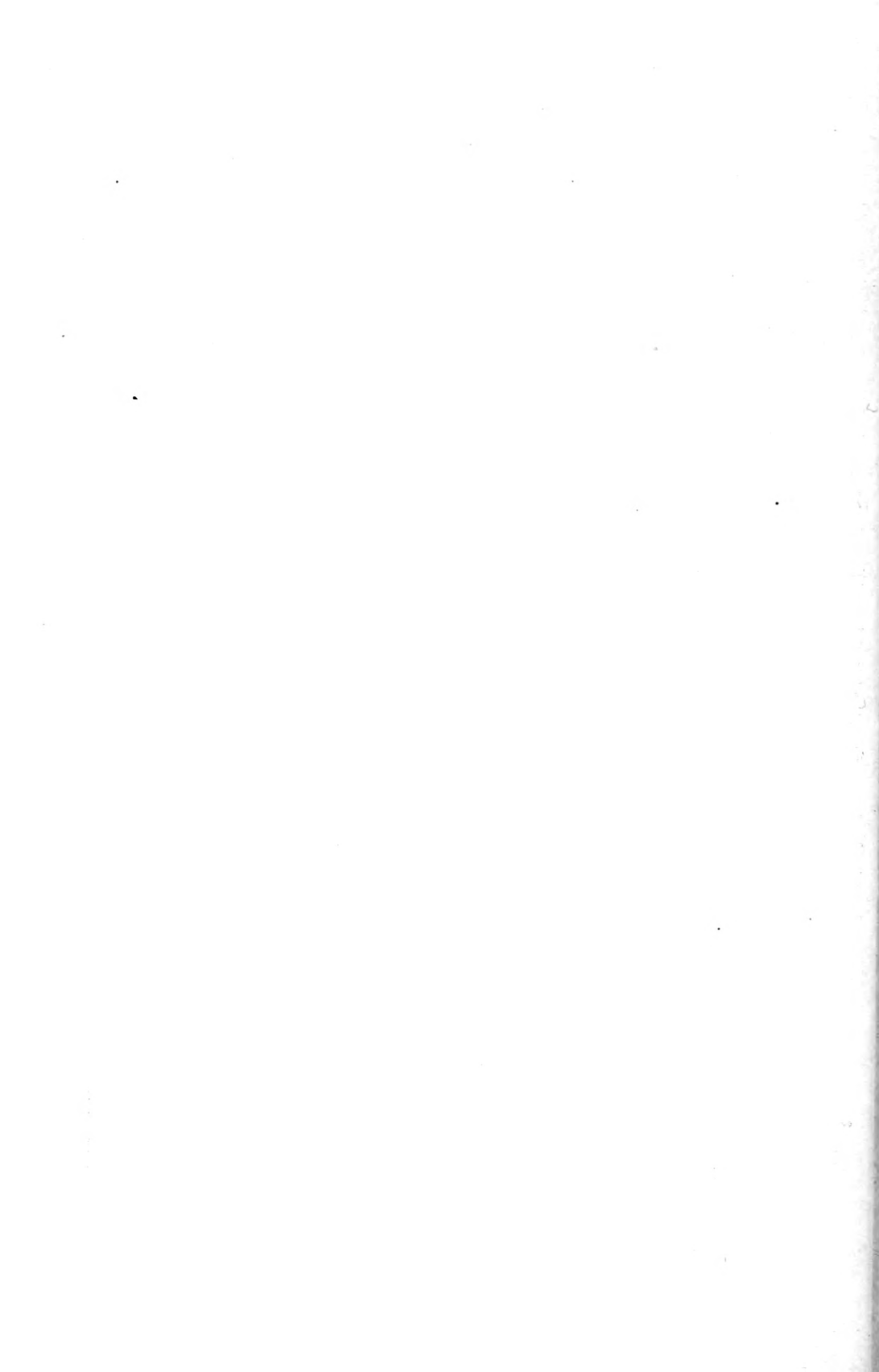
Birefringence: Anomalous weak double refraction with a separation into fields, occurs.

Becomes cloudy on heating strongly; soluble even in thin sections in acids.

**Sodalite group** differs in cleavage and chemically.

**Leucite** is attacked by HCl with difficulty. Analcite takes stain readily. Treating leucite with hydrofluosilicic acid produces isometric potassium fluosilicate crystals, while analcite so treated gives hexagonal crystals of sodium fluosilicate.

**Garnets** have much higher indices.



The mineral is isotropic.

Colorless.

Index of refraction is greater  
than that of Canada balsam.

INDEX > CANADA BALSAM.

*Cut on line.*

The mineral is isotropic, colorless, index of refraction is greater than that of Canada balsam.

(Arranged according to mean indices of refraction.)

**Octahedrons:** generally **quadratic** sections.

**Spinel** . . . . .  $n = 1.716$

**Periclase** . . . . . 1.736

**Polygonal** sections and **rounded** grains.

**Grossular** (garnet) . . . .  $n = 1.750$

**Spessartine** (garnet) . . . . . 1.811



**Spinel.**— $\text{MgO} \cdot \text{Al}_2\text{O}_3$ ,       $H = 7.5-8.0$ ,       $G = 3.6-3.7$ .  
Isometric.

Cleavage: Wanting.

Habit: Generally in sharply defined quadratic (111) crystals.

Colorless to faint red, green, or blue.

Index:  $n = 1.712-1.720$ .

Not affected by acids. Never altered.

**Periclase** is gray to yellow and has good cleavage.

**Periclase.**— $\text{MgO}$ ,       $H = 6.0$ ,       $G = 3.642-3.674$   
Isometric.

Cleavage: Good (100).

Habit: Grains, crystals (111).

White, gray, dark gray, yellow to brownish yellow.

Index:  $n_{na} = 1.736$ .

Dissolves in hot concentrated  $\text{HCl}$ ; is colored brown in thin sections when moistened with silver nitrate.

**Spinel**, see above.

**Grossular.**— $\text{Ca}_3\text{Al}_2\text{Si}_3\text{O}_{12}$ ,       $H = 7.0-7.5$ ,       $G = 3.42-3.72$   
Isometric.

Cleavage: Strong, irregular fractures.

Habit: (110), quadratic, hexagonal, or octagonal outlines, or irregular rounded grains.

Colorless to weak yellowish.

Index:  $n_{na} = 1.744-1.757$ .

Birefringence: Optical anomalies.

Insoluble in acids. Zonal structure common.

**Periclase** and **spinel**: Separate by specific gravity, then test for  $\text{SiO}_2$ .

**Periclase** has a good cleavage.

**Spinel** is generally in (111) crystals.

**Spessartine.**— $\text{Mn}_3\text{Al}_2\text{Si}_3\text{O}_{12}$ ,       $H = 7.0-7.5$ ,       $G = 4.0-4.3$ .  
Isometric.

Cleavage: Strong, irregular fractures.

Habit: (110) grains; quadratic, etc., outlines.

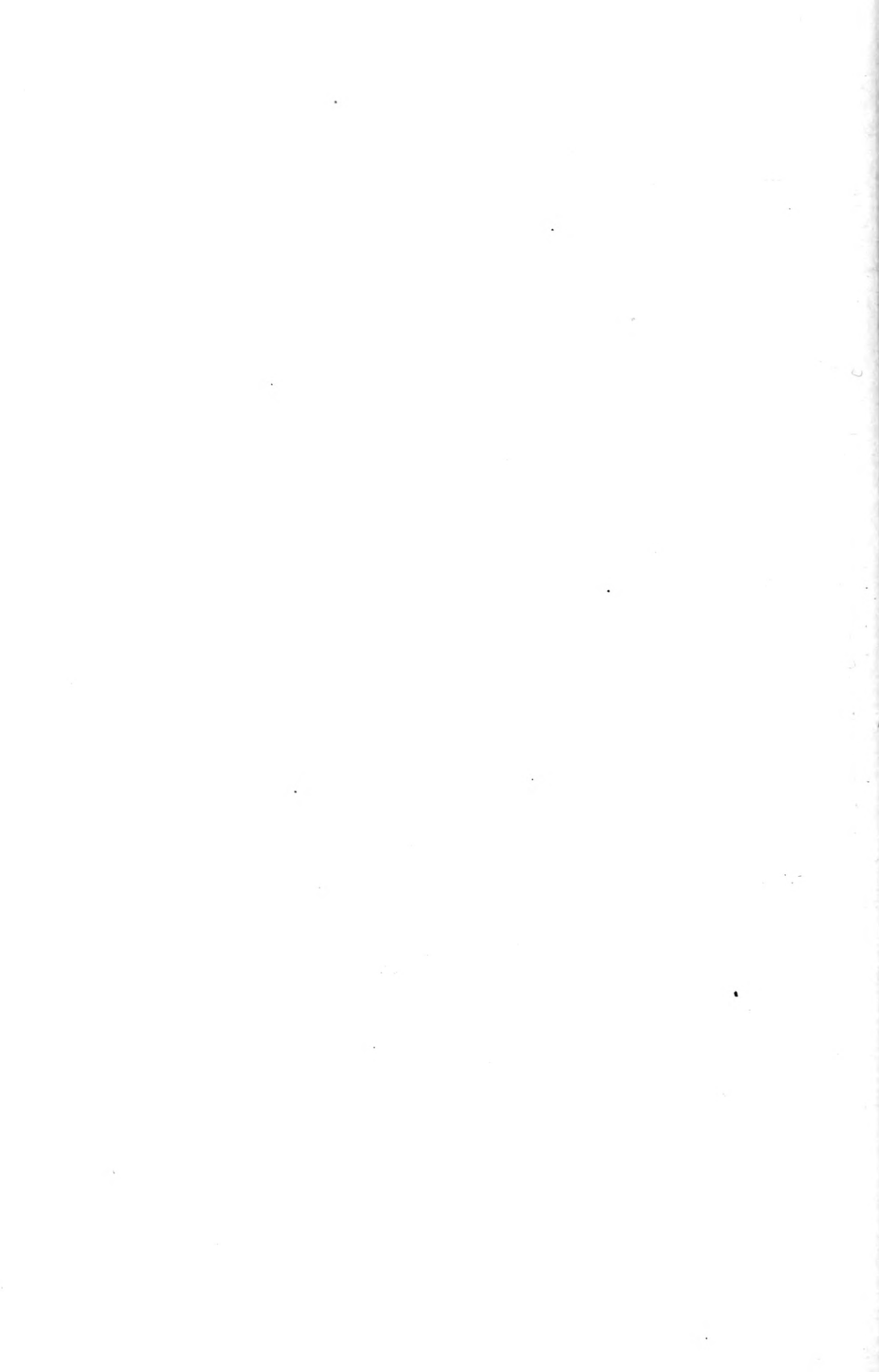
Blood-red, yellowish red, red-brown, colorless.

Index:  $n_{na} = 1.8105$ .

Birefringence: Optical anomalies.

Insoluble in acids.

**Spinel**, **periclase**, see above.

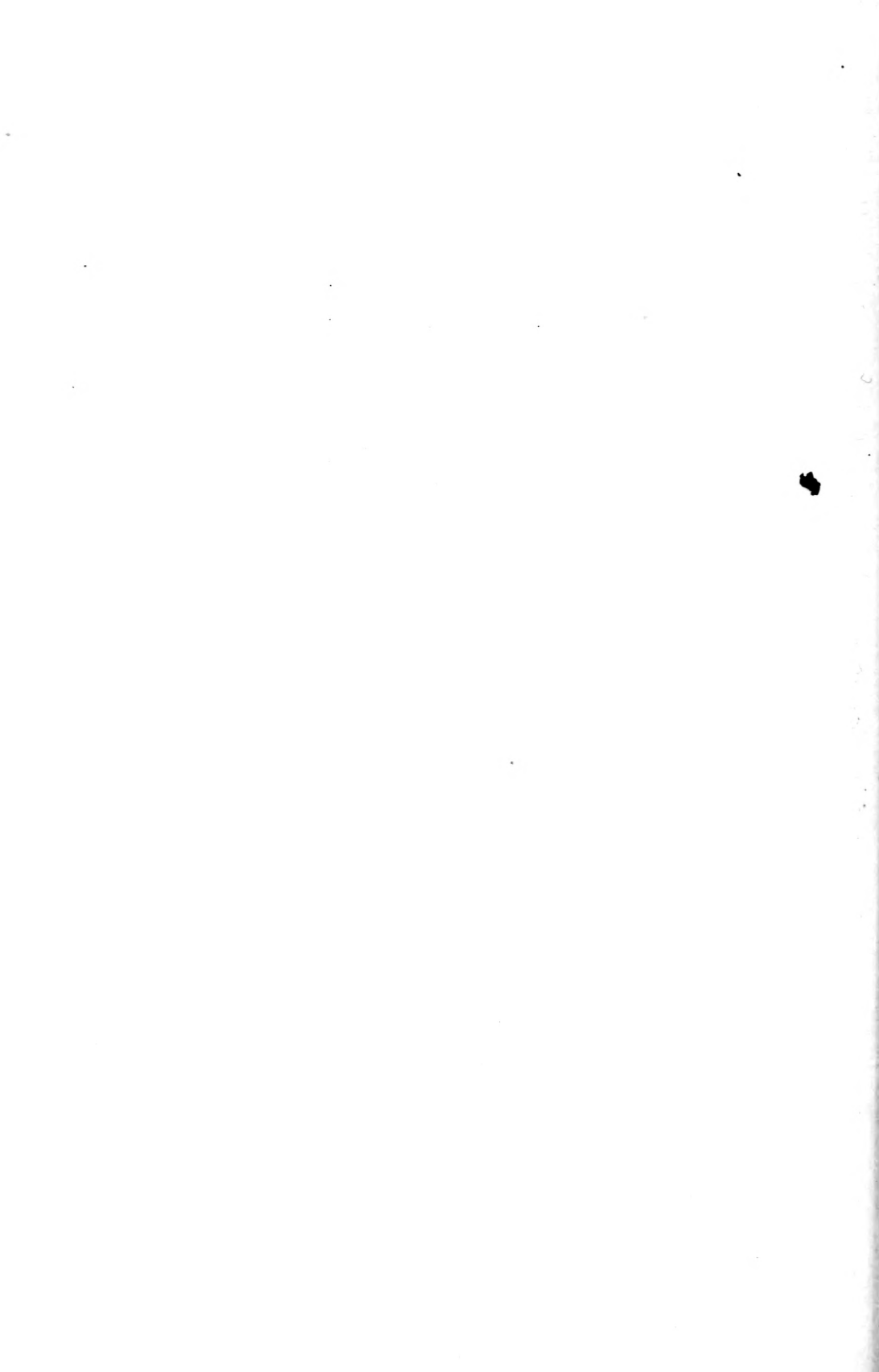


The mineral is isotropic.

Colored.

COLORED.

*Cut on line.*



The mineral is isotropic.

Colored.

Index of refraction is less than that  
of Canada balsam.

INDEX < CANADA BALSAM.

*Cut on line.*

The mineral is isotropic, colored, index of refraction is less than  
that of Canada balsam.

(Arranged according to mean indices of refraction.)

The mineral forms <b>crystals</b> . . .	<b>Fluorite</b> . . . . .	$n = 1.433$
	<b>Sodalite</b> . . . . .	1.483
	<b>Foselite</b> . . . . .	1.490
	<b>Häüynite</b> . . . . .	1.503
	<b>Leucite</b> . . . . .	1.508
<b>Amorphous filling</b> . . . . .	<b>Glass</b> . . . . .	$n = 1.490$

**Fluorite.**—  $\text{CaF}_2$ ,  $\text{H} = 4.0$ ,  $\text{G} = 3.18\text{--}3.20$ .

Isometric.

Cleavage: Perfect (111).

Habit: Seldom shows crystal form; generally cavity and inter-space filling, or irregular or drop-like grains.

Colorless to violet or purple. Color often irregularly or zonally distributed.

Index:  $n = 1.4332\text{--}1.4340$ .

With  $\text{H}_2\text{SO}_4$  gives off hydrofluoric acid which will etch glass; very slightly affected by other acids.

**Opal** and **sodalite** groups have higher indices and are often very slightly anisotropic.

**Opal** has no cleavage.

**Sodalite** group is attacked by weak acids and has (110) cleavage.

**Other** colorless minerals usually have lower specific gravities and higher indices.

**Sodalite.**—  $(\text{SiO}_4)_3\text{Al}_2 \cdot \text{AlCl} \cdot \text{Na}_4$ ,  $\text{H} = 5.5$ ,  $\text{G} = 2.28\text{--}2.34$ .

Isometric.

Cleavage: Sometimes fair (110).

Habit: Cloudy quadratic, hexagonal, or rounded grains, often distorted.

Colorless, bluish, greenish, light pink, red, yellowish.

Index:  $n_{na} = 1.4827\text{--}1.486$ .

Anomalous double refraction is rare.

Gelatinizes with  $\text{HCl}$ ; crystals of  $\text{NaCl}$  form on drying. Gelatinizes even in thin sections with acetic acid.

**Isotropic grains** (except glass, fluorite, leucite, and analcite) have higher indices.

**Glass** has no cleavage and no crystal form.

**Leucite**, **fluorite**, and **analcite** have different cleavage, gelatinize with greater difficulty, have twinning and different chemical reactions.

**Häüynite**, **noselite**, and **lazurite** are separated by chemical tests, cleavage, and crystal form.

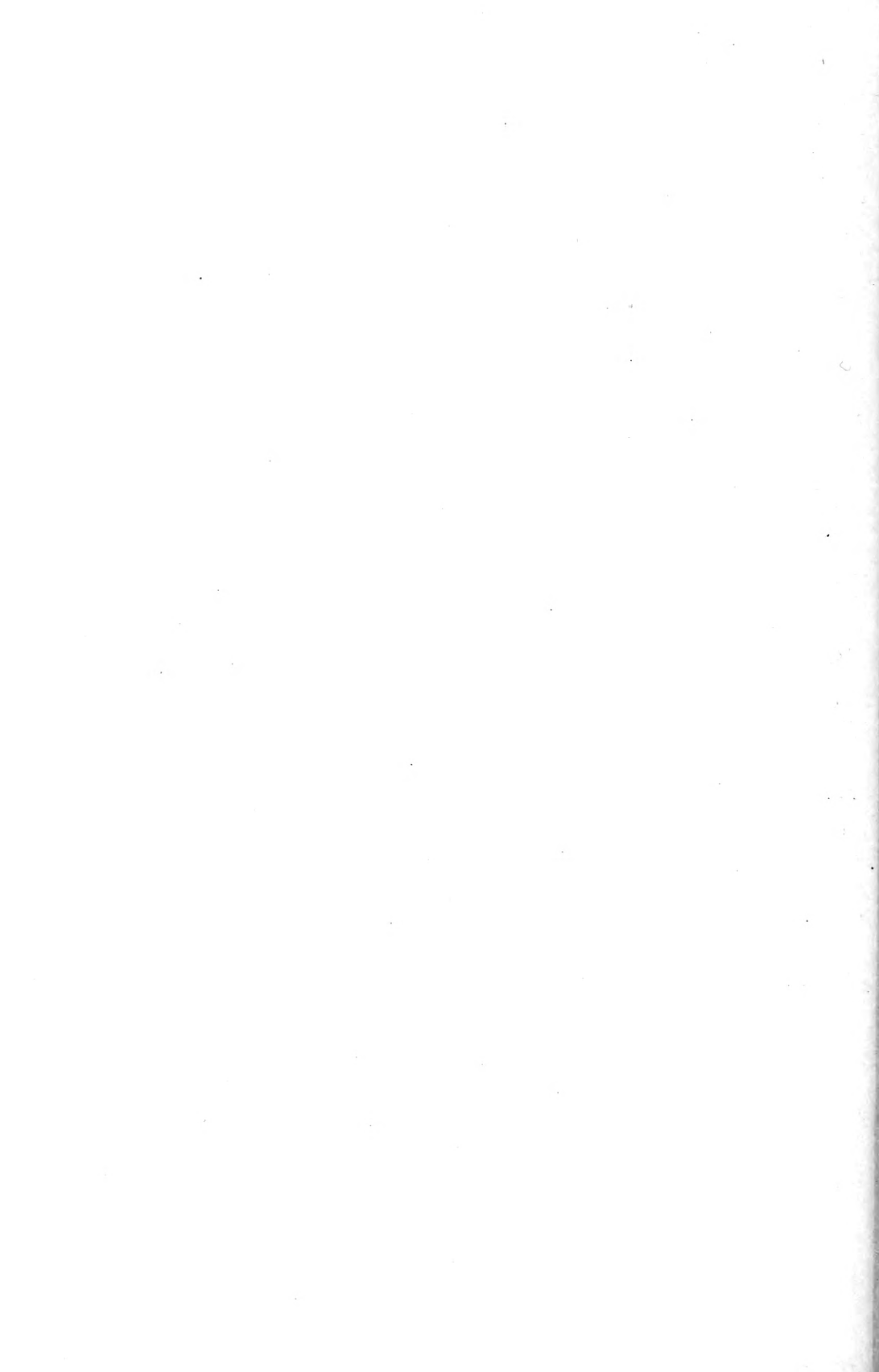
**Noselite.**—  $(\text{SiO}_4)_3\text{Al}_2 \cdot \text{AlSO}_4\text{Na} \cdot \text{Na}$ ,  $\text{H} = 5.5$ ,  $\text{G} = 2.27\text{--}2.50$ .

Isometric.

Cleavage: Usually shows right-angled cleavage in cross-sections parallel to (100) or (110). Sections parallel to (111) show three series of lines cutting each other at  $60^\circ$ .

Habit: Usually occurs in crystals, crystal fragments, or rounded grains.

Colorless, blue, gray, red, yellow, or green. The color is often irregularly distributed or zonal.





Index:  $n_{na} = 1.495$ .

Often has opaque borders and is often altered. Gelatinizes easily with HCl, and few gypsum crystals and many NaCl crystals form. Sometimes shows optical anomalies.

**Haüynite** gives many gypsum crystals in drying gelatine from HCl.

**Sodalite** has less perfect cleavage, and seldom has borders.

**Haüynit** .  $(\text{SiO}_4)_3\text{Al}_2 \cdot \text{AlSO}_4\text{Na} \cdot \text{CaNa}_2$ ,       $H = 5.5$ ,       $G = 2.27-2.50$ .  
Isometric.

Cleavage: Cross-sections parallel to (100) or (110) show two systems at right angles.

Habit: Usually occurs in crystals (110), crystal fragments, or rounded grains.

Colorless, blue, gray, brownish, red, yellow, and green. Color often irregularly distributed or zonal.

Index:  $n_{na} = 1.496-1.504$ .

Sometimes shows optical anomalies either about inclusions or as a dark cross. Haüynite usually contains inclusions at the center or around periphery. It is often altered. Gelatinizes easily with HCl, and gypsum crystals result from the drying gelatine.

**Noselite** gives few gypsum crystals.

**Sodalite** has less perfect cleavage and seldom has borders.

**Leucite**.—  $\text{KAlSi}_3\text{O}_8$ ,       $H = 5.5-6.0$ ,       $G = 2.45-2.5$ .  
Isometric.

Cleavage: Not noticeable, irregular cracks.

Habit: Six- or eight-sided to rounded grains. Very often contains inclusions in regular zones.

Colorless to gray.

$\omega = 1.508$ ,  $\epsilon = 1.509$ .

Birefringence: Very low,  $= 0.01$ . Optical anomalies; shows polysynthetic twinning.

HCl attacks leucite slightly in thin sections, but the powdered mineral is dissolved with a separation of silica.

**All minerals but analcite** differ from leucite in having higher indices and higher double refraction. The twinning and crystal form of leucite also distinguish it.

**Analcite and sodalite group** may be confused with isotropic leucite. Either may be distinguished by the greater resistance of leucite to HCl and by its micro-chemical reactions, giving isometric potassium fluosilicate crystals, while analcite gives hexagonal sodium fluosilicate crystals.



The mineral is isotropic.

Colored.

Index of refraction is greater  
than that of Canada balsam.

INDEX > CANADA BALSAM.

*Cut on line.*

The mineral is isotropic, colored, index of refraction is greater than that of Canada balsam.

(Arranged according to mean indices of refraction.)

Generally octahedrons or quadratic sections.

<b>Spinel</b> . . . . .	$n = 1.718$
<b>Periclase</b> . . . . .	1.736
<b>Hercynite</b> (spinel) . .	1.749
<b>Picotite</b> (spinel) . . .	1.7 ca.
<b>Gahnite</b> (spinel) . . .	1.765
<b>Pleonaste</b> (spinel) . .	high
<b>Pyrrhite</b> . . . . .	high
<b>Beckelite</b> . . . . .	high
<b>Chromite</b> . . . . .	2.097
<b>Perovskite</b> . . . . .	2.38

Rounded, quadratic, hexagonal, octahedral, etc., or irregular grains. Usually strong, irregular fractures. Generally completely isotropic or faint optical anomalies. Often show zonal structure.

<b>Grossular</b> (garnet) . . .	$n = 1.744$
<b>Pyrope</b> " . . .	1.744
<b>Almandine</b> " . . .	1.810
<b>Spessartine</b> " . . .	1.811
<b>Uwarowite</b> " . . .	1.838
<b>Melanite</b> " . . .	1.856

Spinel—  $\text{MgO} \cdot \text{Al}_2\text{O}_3$ ,  $\text{H} = 7.5\text{--}8.0$ ,  $\text{G} = 3.6\text{--}3.7$ .  
Isometric.

Cleavage: Wanting.

Habit: Generally in sharply defined quadratic (111) crystals.

Colorless to faint red, green, or blue.

Index:  $n = 1.712\text{--}1.720$ .

Not affected by acids. Never altered.

Periclase is gray to yellow and has good cleavage.

Periclase— $\text{MgO}$ ,  $\text{H} = 6.0$ ,  $\text{G} = 3.642\text{--}3.674$ .

Isometric.

Cleavage: Good (100).

Habit: Grains, crystals (111).

White, gray, dark gray, yellow to brownish yellow.

Index:  $n_a = 1.736$ .

Dissolves in hot concentrated  $\text{HCl}$ ; is colored brown in thin sections when moistened with silver nitrate.

Spinel, see above.

Hercynite.— $\text{FeO} \cdot \text{Al}_2\text{O}_3$ ,  $\text{H} = 7.5\text{--}8.0$ ,  $\text{G} = 3.91\text{--}3.95$ .

Isometric.

Habit: Grains, crystals (111).

Dark green.

Index:  $n = 1.749$ .

Insoluble in acids.

Pleonaste is only to be separated by chemical means.

Picotite.— $(\text{Mg}, \text{Fe})(\text{Al}, \text{Cr}, \text{Fe})_2\text{O}_4$ ,  $\text{H} = 7.5\text{--}8.0$ ,  $\text{G} = 4.08$ .

Isometric.

Cleavage: Wanting.

Habit: Grains, rarely crystals (111).

Yellow, brown, greenish brown.

Index:  $n = 1.7+$ .

Reaction for chromium.

Chromite is distinguished chemically, by specific gravity, and by hardness.

Gahnite.— $\text{ZnAl}_2\text{O}_4$ ,  $\text{H} = 7.5\text{--}8.0$ ,  $\text{G} = 4.0\text{--}4.6$ .

Isometric.

Cleavage: (111), indistinct.

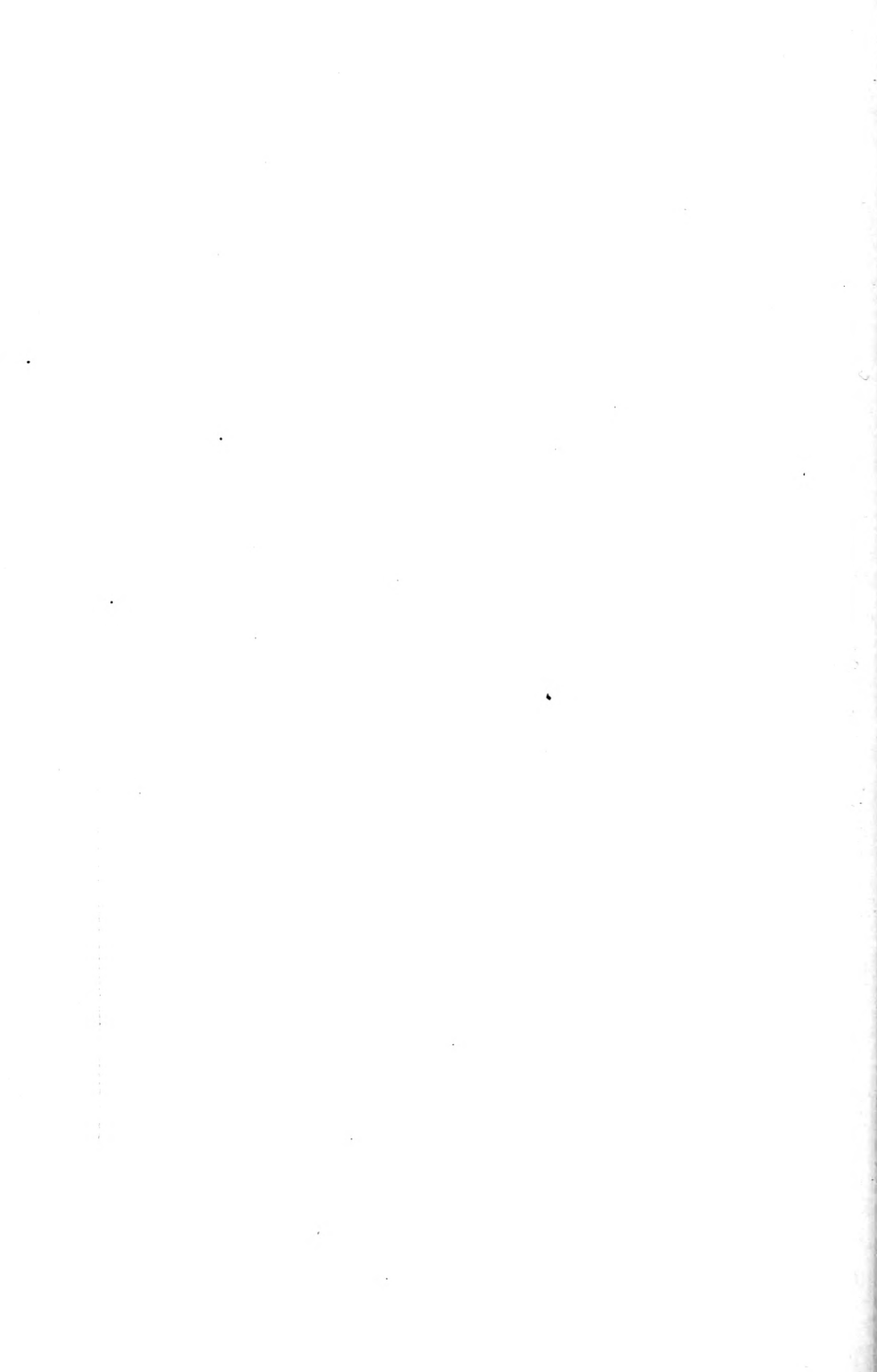
Habit: (111) grains.

Green, greenish black.

Index:  $n = 1.765$ .

Reaction for Zn. Occurs in crystalline schists.

Pleonaste is distinguished chemically.



**Pleonaste.**— $(\text{Mg,Fe})(\text{Al,Fe})_2\text{O}_4$ ,  $H=8.0$ ,  $G=3.82$ .

Isometric.

Cleavage: (111), imperfect.

Habit: Generally in sharply defined (111) quadratic crystals.

Green. By incident light or when opaque it is black without metallic luster.

Index: High.

Insoluble in acids, except concentrated  $\text{H}_2\text{SO}_4$ .

Common in gneisses. Often included in garnets and cordierite.

Gahnite is distinguished chemically.

**Pyrrhite.**—Calcium niobate or tantalate,  $H=5.5$ ,  $G=4.1-4.3$ .

Isometric.

Cleavage: Not observed.

Habit: Crystals (111).

Orange-yellow to red.

Index: High.

Insoluble in HCl.

Spinel is much harder.

**Beckelite.**— $\text{Ca}_2(\text{Ce,L a,D i})_4\text{Si}_3\text{O}_{16}$ ,  $H=5.0$ ,  $G=\text{ca. } 4.15$ .

Isometric.

Cleavage: (100) distinct.

Habit: Grains (111), (110).

Light yellow.

Index: High.

Birefringence: Large crystals show optical anomalies.

**Chromite.**— $\text{FeCr}_2\text{O}_4$ ,  $H=5.5$ ,  $G=4.32-4.57$ .

Isometric.

Cleavage: Wanting.

Habit: Irregular grains, crystals (111).

Opaque. By incident light, brownish black; same on thin edges.

Index:  $n=2.0965$ .

Insoluble in acids. Chromium reaction with soda.

**Perovskite.**— $\text{CaTiO}_3$ ,  $H=5.5$ ,  $G=4.02-4.04$

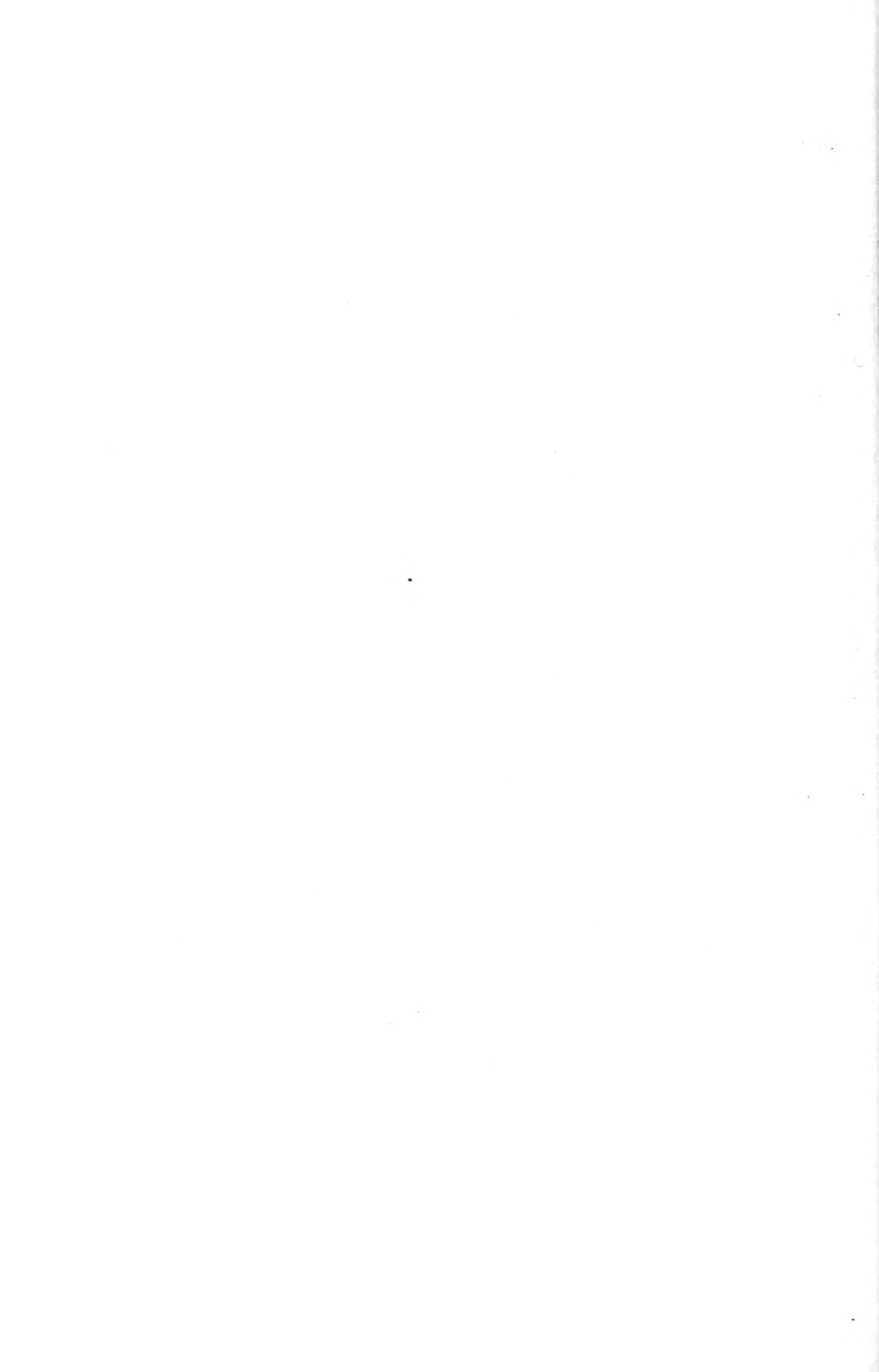
Isometric.

Cleavage: In large individuals distinct (100). Not seen in thin sections.

Habit: Octahedrons (111); sharp, sometimes rounded, cubes.

Grayish white, violet-gray, brownish to red-brown, rarely greenish gray.

Index:  $n_{na}=2.38$ .





Anomalous double refraction in large individuals; often not seen in thin sections.

Insoluble in HCl, not magnetic, Ti reaction.

**Ilmenite** and **hematite** resemble perovskite when opaque, but are soluble in HCl and show different crystal outlines or are irregular.

**Chromite**, **picotite**, and **melanite** may be separated by combining specific gravity, solubility in HCl, and attraction by the magnet. In the separated material perovskite will show the presence of Ti, melanite will show  $\text{SiO}_2$ , and chromite Cr.

**Grossular.**— $\text{Ca}_3\text{Al}_2\text{Si}_3\text{O}_{12}$ ,       $H=7.0-7.5$ ,       $G=3.42-3.72$ .

Isometric.

Cleavage: Wanting; shows irregular cracks.

Habit: (110), quadratic, hexagonal, or octagonal outlines or irregular rounded grains.

Colorless to weak yellowish.

Index:  $n_{na}=1.744-1.757$ .

Birefringence: Optical anomalies.

Insoluble in acids. Zonal structure common.

**Spinel** and **periclase** are separated by their specific gravities; then tested for  $\text{SiO}_2$ .

**Periclase** has a good cleavage.

**Spinel** is generally in (111) crystals.

**Pyrope.**— $\text{Mg}_3\text{Al}_2\text{Si}_3\text{O}_{12}$ ,       $H=7.0-7.5$ ,       $G=3.7-3.8$ .

Isometric.

Cleavage: Wanting; shows irregular cracks.

Habit: Rounded grains, never crystals.

Red to blood-red.

Index:  $n=1.741-1.750$ .

Kelyphite rims common. Occurs only in peridotites and their derivatives.

**Spinel**s are separated by their specific gravities and the absence of  $\text{SiO}_2$ .

**Almandine.**— $\text{Fe}_3\text{Al}_2\text{Si}_3\text{O}_{12}$ ,       $H=7.0-7.5$ ,       $G=4.1-4.3$ .

Isometric.

Cleavage: Wanting; shows irregular fractures.

Habit: (110), (211), and grains. Quadratic, hexagonal, etc., outlines.

Red, in various tones, to brownish red.

Index:  $n_{na}=1.808-1.811$ .

Optical anomalies appear not to occur.

Insoluble in acids. Zonal structure common.

**Spinel**s are separated by their specific gravities and the absence of  $\text{SiO}_2$ .

*Cut on line.*



**Spessartine.**— $\text{Mn}_3\text{Al}_2\text{Si}_3\text{O}_{12}$ ,       $H = 7.0-7.5$ ,       $G = 4.0-4.3$ .  
Isometric.

Cleavage: Wanting; shows irregular cracks.

Habit: (110), grains; quadratic, etc., outlines.

Blood-red, yellowish red, red-brown, colorless.

Index:  $n_{na} = 1.8105$ .

Birefringence: Optical anomalies.

Insoluble in acids.

Spinels and periclase are separated by their specific gravities and the absence of  $\text{SiO}_2$ .

Periclase has good cleavage.

Spinels generally occur in (111) crystals.

**Uwarowite.**— $\text{Ca}_3\text{Cr}_2\text{Si}_3\text{O}_{12}$ ,       $H = 7.5$ ,       $G = 3.51$ .  
Isometric.

Cleavage: Wanting; irregular cracks.

Habit: (110), grains.

Deep green.

Index:  $n = 1.838$ .

Usually shows optical anomalies.

Alteration unknown. Confined to Cr rich serpentines, granular limestones, and dolomites.

Spinels are separated by their color, specific gravities, and the absence of  $\text{SiO}_2$ .

**Melanite.**— $\text{Ca}_3\text{Fe}_2\text{Si}_3\text{O}_{12}$ ,       $H = 7.0-7.5$ ,       $G = 3.8-4.1$ .  
Isometric.

Cleavage: Wanting; shows irregular cracks.

Habit: Grains and crystals (110), (211).

Various tones of brown, sometimes green.

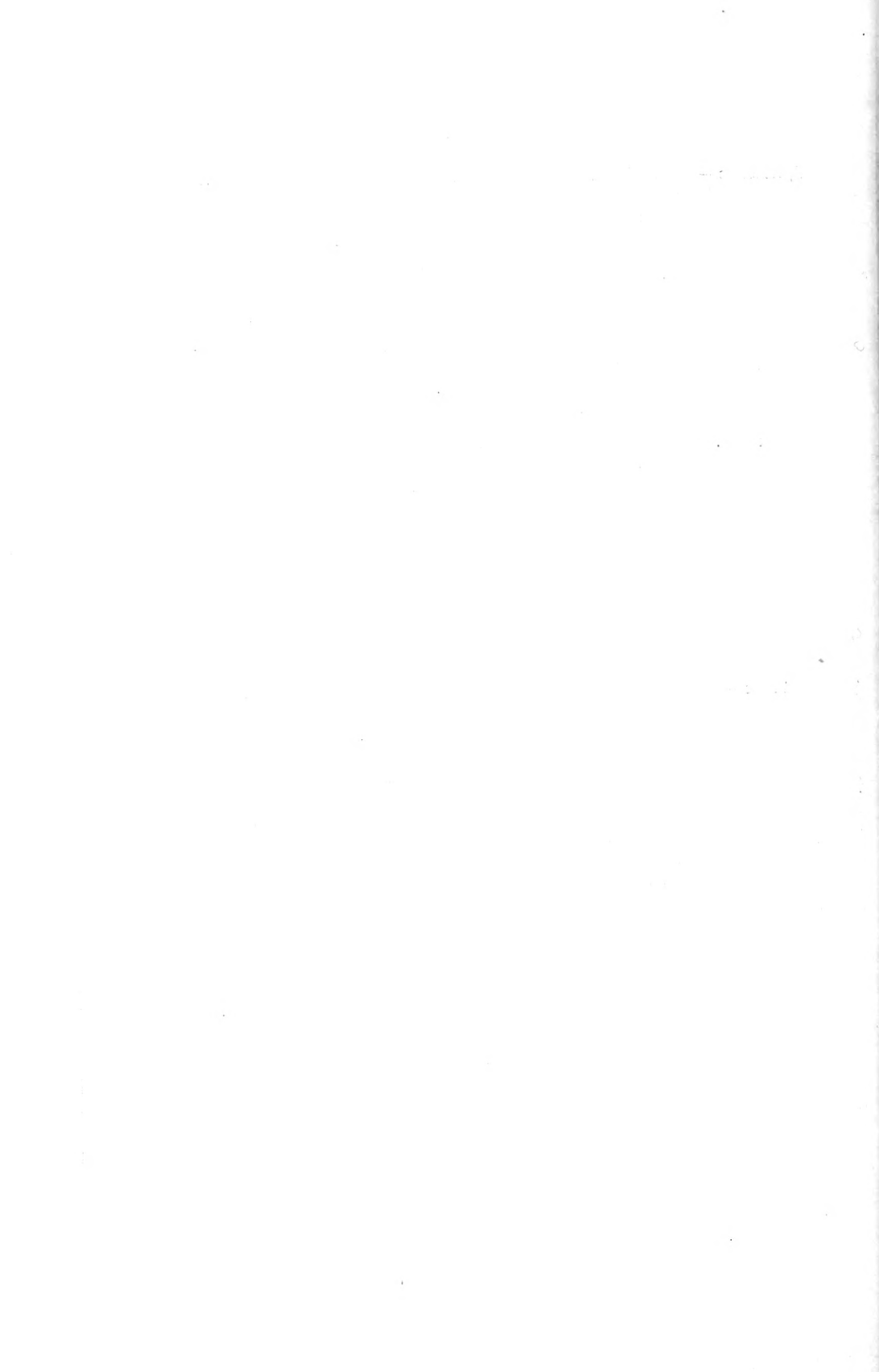
Index:  $n_{na} = 1.8566$ .

Optical anomalies, owing to deep color, hardly observable.

Zonal structure very common. Alterations wanting.

Occurs in phonolites, nephelites, tephrites, etc.

Spinels are separated by their specific gravities, the absence of  $\text{SiO}_2$ , by crystal form, and want of zonal structure.



The mineral is **anisotropic**.

**ANISOTROPIC.**



The mineral is anisotropic.

Parallel extinction.

PARALLEL EXTINCTION.

*Cut on line.*





The mineral is **anisotropic**.

Parallel extinction.  
Colorless.

COLORLESS.

*Cut on line.*



The mineral is anisotropic.

Parallel extinction.

Colorless.

Index of refraction is less than  
that of Canada balsam.

INDEX < CANADA BALSAM.

*Cut on line.*



The mineral is anisotropic.

Parallel extinction.

Colorless.

Index of refraction is less than  
that of Canada balsam.

Maximum birefringence is less  
than that of quartz.

BIREFRINGENCE < QUARTZ.

*Cut on line.*



The mineral is anisotropic.

Parallel extinction.

Colorless.

Index of refraction is less than  
that of Canada balsam.

Maximum birefringence is less  
than that of quartz.

Uniaxial.

UNIAXIAL.

*Cut on line.*

The Mineral is ANISOTROPIC, has PARALLEL EXTINCTION, is COLORLESS, INDEX OF REFRACTION < Canada balsam, MAXIMUM BIREFRINGENCE < Quartz, UNIAXIAL.										
The Mineral is NEGATIVE (-).					The Mineral is POSITIVE (+).					
← Increase in Index of Refraction. →										
1.55	1.50	1.45	1.40	1.35	In. OF 925 g BIREFR.	1.35	1.40	1.45	1.50	1.55
The Index of Refraction is LOW.						The Index of Refraction is LOW.				
					.001				Opal. *	Leucite. *
					.002				Tridymite.	
Chabazite.					.003					
					.004					
Nephelite.					.005					
					.006					
					.007					
					.008					
					.009					
					.010				Chalcedony.	

\* Opal and Leucite often have anomalous double refraction.



**Chabazite.**— $(\text{Ca}, \text{Na}_2)\text{Al}_2\text{Si}_4\text{O}_{12} + 6\text{H}_2\text{O}$  usually,  $H = 4.0-5.0$ ,  $G = 2.08-2.16$ .

Hexagonal. (—).

Cleavage: Rhombohedral, rather distinct.

Habit: Amorphous; rhombohedrons varying little from the cube.

White, flesh-red.

Index: 1.5, mean.

Birefringence: 0.003.

Optical anomalies; interference figure usually confused, sometimes distinctly biaxial.

**Nephelite.**— $\text{NaAlSiO}_4$ ,  $H = 5.5-6.0$ ,  $G = 2.55-2.61$ .

Hexagonal. (—).

Cleavage: (0001) and (10 $\bar{1}$ 0), distinct.

Habit: Short prisms, square sections, or grains.

Elongation: (10 $\bar{1}$ 0), rectangular, quadratic. (—).

Orientation:  $c = a$ .

Colorless.

Pleochroism: None.

$\omega = 1.539-1.542$ ,  $\epsilon = 1.532-1.542$ .

$\omega - \epsilon = 0.005$ .

2E sometimes has anomalous small angle.

Gelatinizes easily with HCl and is readily stained. In the drying gelatine, cubes of NaCl are formed.

**Sodalite** minerals have lower indices and no double refraction.

**Apatite**, **gehlenite**, and **melilite** have higher indices.

**Scapolites** have higher indices and higher double refraction. Different cleavage.

**Sanidine** and **orthoclase** have lower double refraction and are unaffected by HCl. They are biaxial.

*Cut on line.*



**Opal.**—  $\text{SiO}_2 + \text{aq.}$ ,  $H = 5.5-6.5$ ,  $G = 1.9-2.3$ .  
 Amorphous.  
 Cleavage: Wanting.  
 Habit: Irregular grains, vein filling, druses; pseudomorphs after feldspar, augite, or other silicates  
 Transparent, colorless.  
 Index: Low. Varies with aq. contents; mean 1.36–1.45.  
 Birefringence: Anomalous double refraction in spots is not unusual.  
 Insoluble in acids.

**Tridymite** occurs in tabular, hexagonal, or rounded grains, sometimes in rosettes.

**Leucite.**—  $\text{KAlSi}_2\text{O}_6$ ,  $H = 5.5-6.0$ ,  $G = 2.45-2.5$ .  
 Isometric.  
 Cleavage: Not noticeable; irregular cracks.  
 Habit: Six- and eight-sided to rounded grains. Very often contains inclusions in regular zones.  
 Colorless to gray.  
 $\omega = 1.508$ ,  $\varepsilon = 1.509$ .

Birefringence: Very low, .001. Optical anomalies; shows polysynthetic twinning.

HCl attacks leucite slightly in thin sections, but dissolves the powdered mineral with a separation of silica.

Other minerals which are anisotropic have higher double refraction.

Opal has no crystal form.

**Tridymite.**—  $\text{SiO}_2$ ,  $H = 6.5$ ,  $G = 2.28-2.33$ .  
 Hexagonal. (+).  
 Cleavage: None to be seen.  
 Habit: Tabular, hexagonal, or rounded crystals; aggregates in rosettes.  
 Elongation: (0001), lath-shaped. (-).  
 Colorless.  
 Pleochroism: None.  
 $\omega = 1.477$ .

$\varepsilon - \omega = 0.002$ .

$2E =$  as high as  $70^\circ$ ; anomalous.

Insoluble in acids. Optical anomalies; sometimes biaxial and separates into sectors.

Other minerals: The form of the tridymite crystals and their aggregation, in combination with the very low index and double refraction, separate tridymite from all other minerals.

*Cut on line.*



**Chalcedony.**— $\text{SiO}_2 + \text{aq.}$ ,  $H = 6.0-7.0$ ,  $G = 2.59-2.64$ .

Orthorhombic. (+).

Cleavage: None.

Habit: Thread-like aggregates, spherulites, concretionary masses, etc.

Elongation:  $(110)$ :  $(1\bar{1}0)$ , thread-like. (-).

Orientation:  $c = a$ .

Colorless, yellowish, brownish.

Pleochroism: Wanting.

$\alpha = 1.533$ ,  $\beta = 1.536$ ,  $\gamma = 1.544$ .

$\gamma - \alpha = 0.011$ ,  $\gamma - \beta = 0.008$ ,  $\beta - \alpha = 0.003$ .

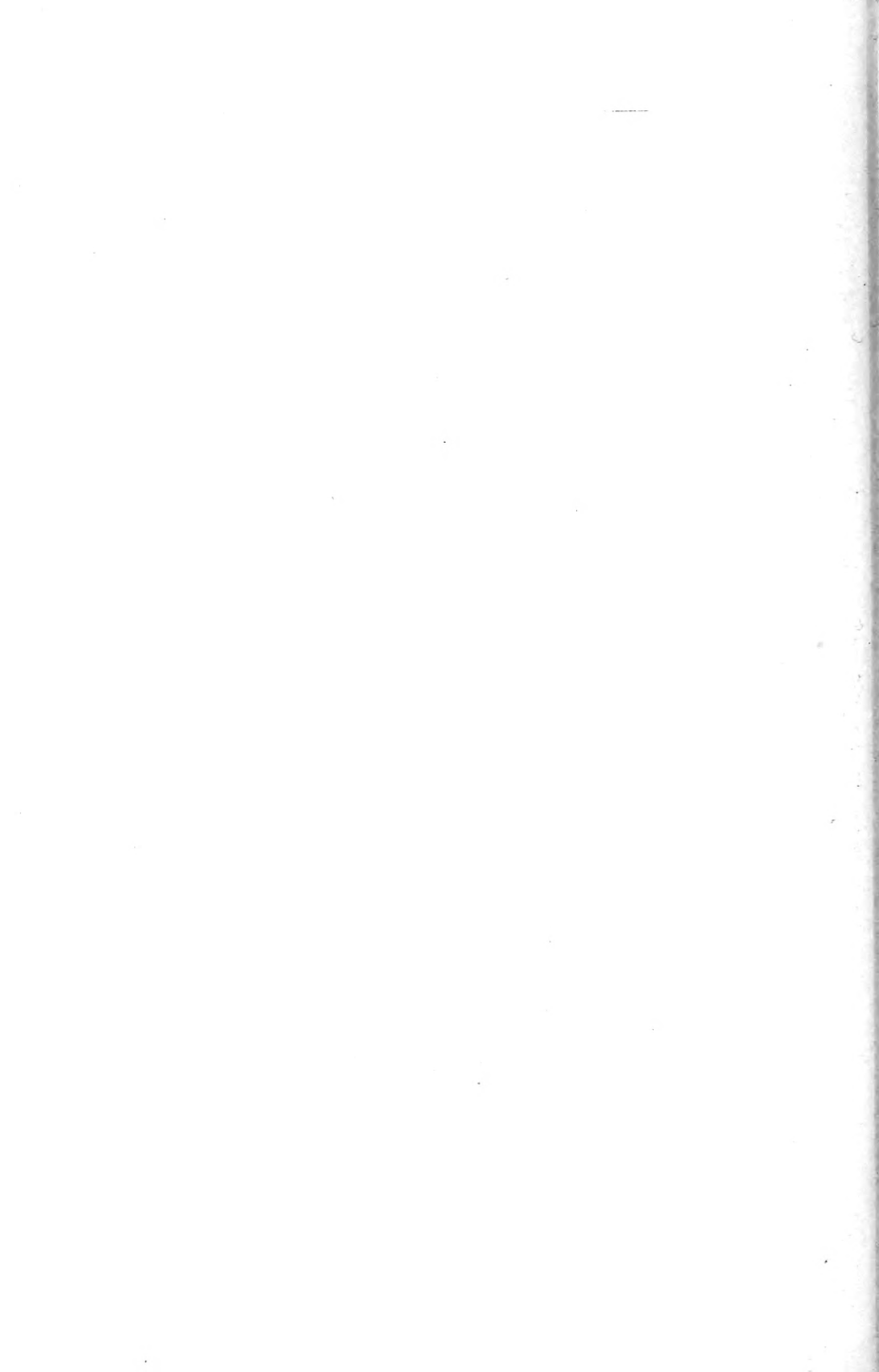
$2V = 10^\circ-40^\circ$ . Sometimes appears nearly uniaxial.

Chemically like quartz.

Zeolites are not thread-like and gelatinize with acids.

Pseudochalcedony is optically (-) and has smaller double refraction.

*Cut on line.*



The mineral is anisotropic.

Parallel extinction.

Colorless.

Index of refraction is less than  
that of Canada balsam.

Maximum birefringence is less  
than that of quartz.

Biaxial.

BIAXIAL.

*Cut on line.*





**Orthoclase.**— $\text{KAlSi}_3\text{O}_8$ ,  $H = 6.0\text{--}6.5$ ,  $G = 2.54\text{--}2.56$ .

Monoclinic. (—).

Cleavage: Good (001), (010). (001):(010) =  $90^\circ$ .

Habit: Plates, prisms, grains. Carlsbad twinning **very common**.

Elongation: (001):(010) laths, (—).

(110):(110) plates, ( $\pm$ ).

Orientation:  $b = c$ ,  $a : a = \pm 5^\circ$  ca.

Colorless.

Pleochroism: None.

$\alpha = 1.519$ ,  $\beta = 1.523$ ,  $\gamma = 1.525$ .

$\gamma - \alpha = 0.006$ ,  $\gamma - \beta = 0.002$ ,  $\beta - \alpha = 0.004$ .

Dispersion: Very plain,  $\rho > \nu$ .

$2V = 70^\circ\text{--}80^\circ$ ,  $2E_{na} = 120^\circ$  ca.

Insoluble in HCl.

Plagioclase, except albite, and other colorless minerals differ generally in having higher indices and double refraction.

Nephelite gives uniaxial figure and is acted upon by HCl.

Scapolites, with low indices, have higher double refraction.

Quartz and cordierite have no cleavage, and have indices higher than Canada balsam.

Soda-orthoclase has a higher extinction angle,  $a : a = 10^\circ\text{--}12^\circ$ .

(See also special methods for the separation of the feldspars in Part II.)

**Sanidine.**— $\text{KAlSi}_3\text{O}_8$ ,  $H = 6.0\text{--}6.5$ ,  $G = 2.54\text{--}2.56$ .

Monoclinic. (—).

Cleavage: (001), (010), good.

Habit: Plates, prisms, grains. Carlsbad twins frequent.

Elongation: (001):(010), laths.

(110):(110), plates.

Orientation:  $b = c$ ,  $a : a = +5^\circ$  ca.; or  $b = b$ ,  $a : a = +5^\circ$  ca.

Colorless.

Pleochroism: None.

$\alpha = 1.519$ ,  $\beta = 1.523$ ,  $\gamma = 1.525$ .

$\gamma - \alpha = 0.006$ ,  $\gamma - \beta = 0.002$ ,  $\beta - \alpha = 0.004$ .

Dispersion for  $b = c$ ,  $\rho > \nu$ ; for  $b = b$ ,  $\rho < \nu$ .

$2V = \text{small to } 0^\circ$ .

Insoluble in HCl.

From other minerals, like orthoclase.

Orthoclase has larger value for  $2V$ .

**Oligoclase.**— $\text{Ab}_3\text{An}_1$  to  $\text{Ab}_2\text{An}_1$ ,  $H = 6.0\text{--}7.0$ ,  $G = 2.64\text{--}2.66$ .

Triclinic. (—).

Cleavage: (001), (010), good. (001):(010) =  $86^\circ 32'$ .

Habit: Plates, prisms, grains. Polysynthetic twinning.

Elongation: (001):(010) and (110):(110).

Orientation:  $A_{001} = +1^\circ$ ,  $A_{010} = +4.5^\circ$ .

Colorless.

Pleochroism: None.

Cut on line.



$\alpha = 1.540$ ,  $\beta = 1.544$ ,  $\gamma = 1.547$ .

$\gamma - \alpha = 0.007$ ,  $\gamma - \beta = 0.003$ ,  $\beta - \alpha = 0.004$ .

Dispersion:  $\rho > \nu$ .

$2V = 90^\circ - 98^\circ$ .

(See special methods for the determination of the feldspars in Part II.)

**Microcline.**— $\text{KAlSi}_3\text{O}_8$ ,  $H = 6.0$ ,  $G = 2.54$ .

Triclinic. (—).

Cleavage: (001), (010), good. (001):(010) =  $89^\circ 30'$ .

Habit: Plates, prisms, grains. Polysynthetic twinning, albite and pericline laws.

Elongation: (001):(010) laths.

(110):(110) plates.

Orientation:  $A_{001} = +16^\circ$ ,  $A_{010} = +5^\circ$ .

Colorless.

Pleochroism: None.

$\alpha = 1.519$ ,  $\beta = 1.523$ ,  $\gamma = 1.526$ .

$\gamma - \alpha = 0.007$ ,  $\gamma - \beta = 0.003$ ,  $\beta - \alpha = 0.004$ .

Dispersion:  $\rho > \nu$ .

$2V = 71^\circ - 84^\circ$ .

Insoluble in acids.

Other minerals are separated by the cleavage, low indices, and low double refraction of microcline, which has indices always lower than Canada balsam, lime-soda feldspars, or nephelite. Only to be confused with orthoclase or anorthoclase.

**Orthoclase** has not the "grating" texture of microcline.

Optical behavior on (001) and (010) faces is different.

**Anorthoclase** has smaller axial angle and different orientation on (001) and (010). Has no "grating" texture.

**Cordierite.**— $\text{Mg}_2\text{Al}_4\text{Si}_5\text{O}_{18}$ ,  $H = 7.0 - 7.5$ ,  $G = 2.59 - 2.66$ .

Orthorhombic. (—).

Cleavage: (010), poor.

Habit: Grains, short prisms. Trillings and polysynthetic twins occur.

Elongation: (110):(110), short laths. (—).

Orientation:  $b = c$ ,  $c = a$ .

Colorless, bluish, yellowish.

Pleochroism: Wanting or weak with  $b > c > a$ .

$\alpha = 1.535$ ,  $\beta = 1.540$ ,  $\gamma = 1.544$ .

$\gamma - \alpha = 0.009$ ,  $\gamma - \beta = 0.004$ ,  $\beta - \alpha = 0.005$ .

Dispersion: Weak,  $\rho < \nu$ .

$2E = 63^\circ - 150^\circ$ .

When treated with HF gives characteristic prismatic crystals of magnesium fluosilicate.

**Quartz** has higher interference colors, is uniaxial, and (+).

Chemically different, reactions as above.

Cut on line.



**Heulandite.**— $\text{H}_4\text{CaAl}_2\text{Si}_6\text{O}_{18} + 3\text{H}_2\text{O}$ ,  $H = 3.5\text{--}4.0$ ,  $G = 2.18\text{--}2.22$ .

Monoclinic. (+).

Cleavage: (010), good.

Habit: Leaves, plates, usually parallel, less often rosette-like.

Elongation: (001):(100), laths, plates. (—)

Orientation:  $b = c$ ,  $a: a$ , very small.

Colorless.

Pleochroism: None.

$\alpha = 1.498$ ,  $\beta = 1.499$ ,  $\gamma = 1.505$ .

$\gamma - \alpha = 0.007$ ,  $\gamma - \beta = 0.006$ ,  $\beta - \alpha = 0.001$ .

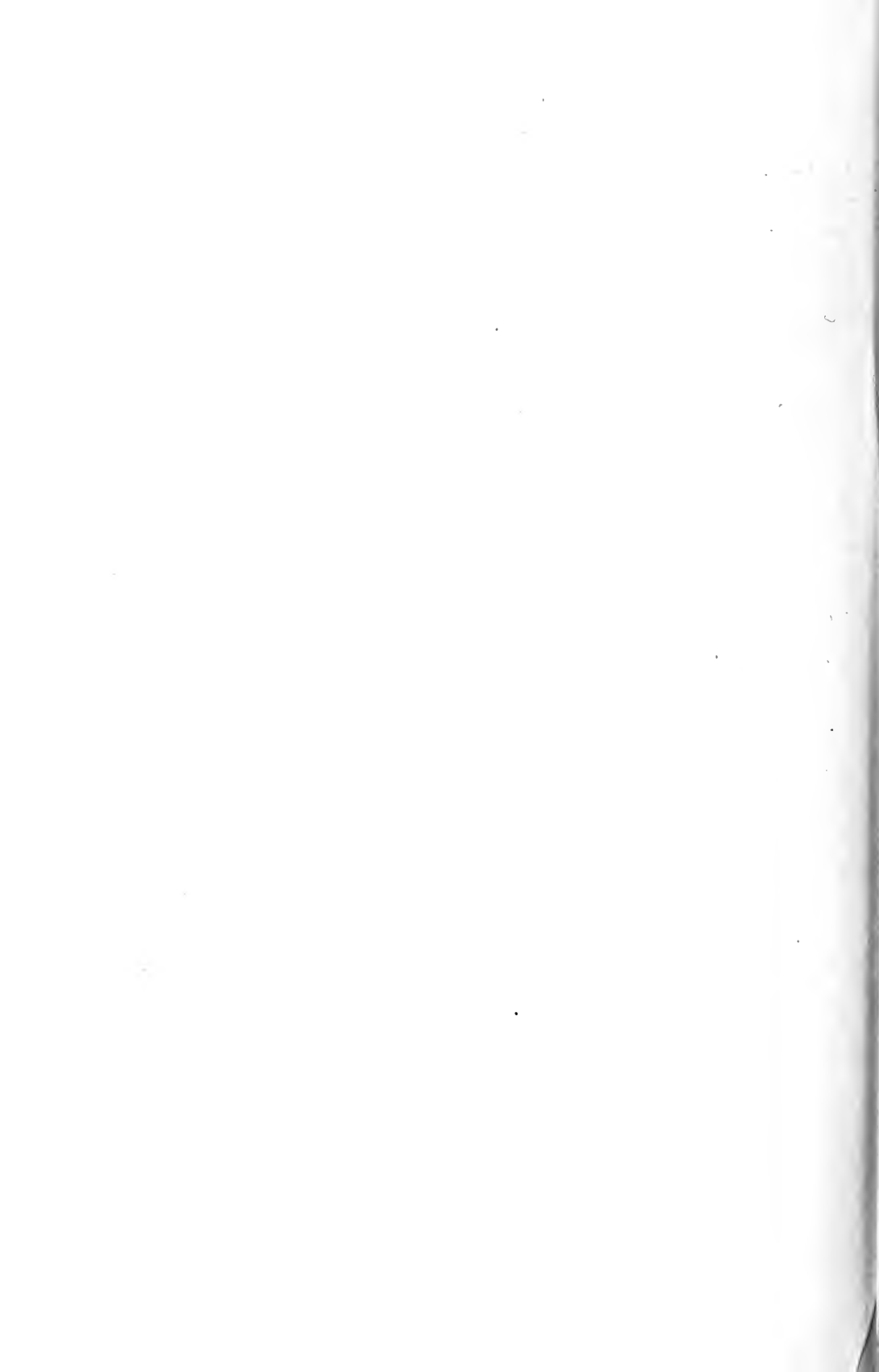
Dispersion:  $\rho < \nu$ , distinctly crossed.

$2E = 0^\circ\text{--}55^\circ$ .

Easily soluble in acids. Strong reactions for Ca and Al.

Other minerals, except other zeolites, have higher indices, usually also different habit.

*Cut on line.*



The mineral is anisotropic.

Parallel extinction.

Colorless.

Index of refraction is less than  
that of Canada balsam.

Maximum birefringence is greater  
than that of quartz.

BIREFRINGENCE > QUARTZ.

*Cut on line.*





The mineral is anisotropic.

Parallel extinction.

Colorless.

Index of refraction is less than  
that of Canada balsam.

Maximum birefringence is greater  
than that of quartz.

Uniaxial.

UNIAXIAL.

*Cut on line.*

The Mineral is ANISOTROPIC, has PARALLEL EXTINCTION, is COLORLESS, INDEX OF REFRACTION < Canada balsam, MAXIMUM BIREFRINGENCE > Quartz, UNIAXIAL.										
The Mineral is NEGATIVE (-).					The Mineral is POSITIVE (+).					
← Increase in Index of Refraction. →										
1.55	1.50	1.45	1.40	1.35	In-crease of BIREFR.	1.35	1.40	1.45	1.50	1.55
The Index of Refraction is LOW.						The Index of Refraction is LOW.				
					.010					
					.015					
					.020					
					.025					
					.030					
					.035					
					.040					
					.045					
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					.070					
					.075					
					.080					
					.085					
					.090					
					.095					
					.100					
					.120					
					.140					
					.160					
					.200					
					.250					

Cancrinite.

Chalcedony.  
Hydronephelite.

**Cancrinite.**— $\text{H}_6\text{Na}_8\text{CaAl}_8(\text{SiO}_4)_8(\text{CO}_3)_2$ ,  $H = 5.0\text{--}6.0$ ,  $G = 2.42\text{--}2.5$ .

Hexagonal. (—).

Cleavage: (1010), good.

Habit: Prisms, needles, grains.

Elongation: (1010), narrow laths, (—).

Colorless, yellow, bluish, reddish.

Pleochroism: None.

$\omega = 1.524$ ,  $\varepsilon = 1.496$ .

$\omega - \varepsilon = 0.028$ .

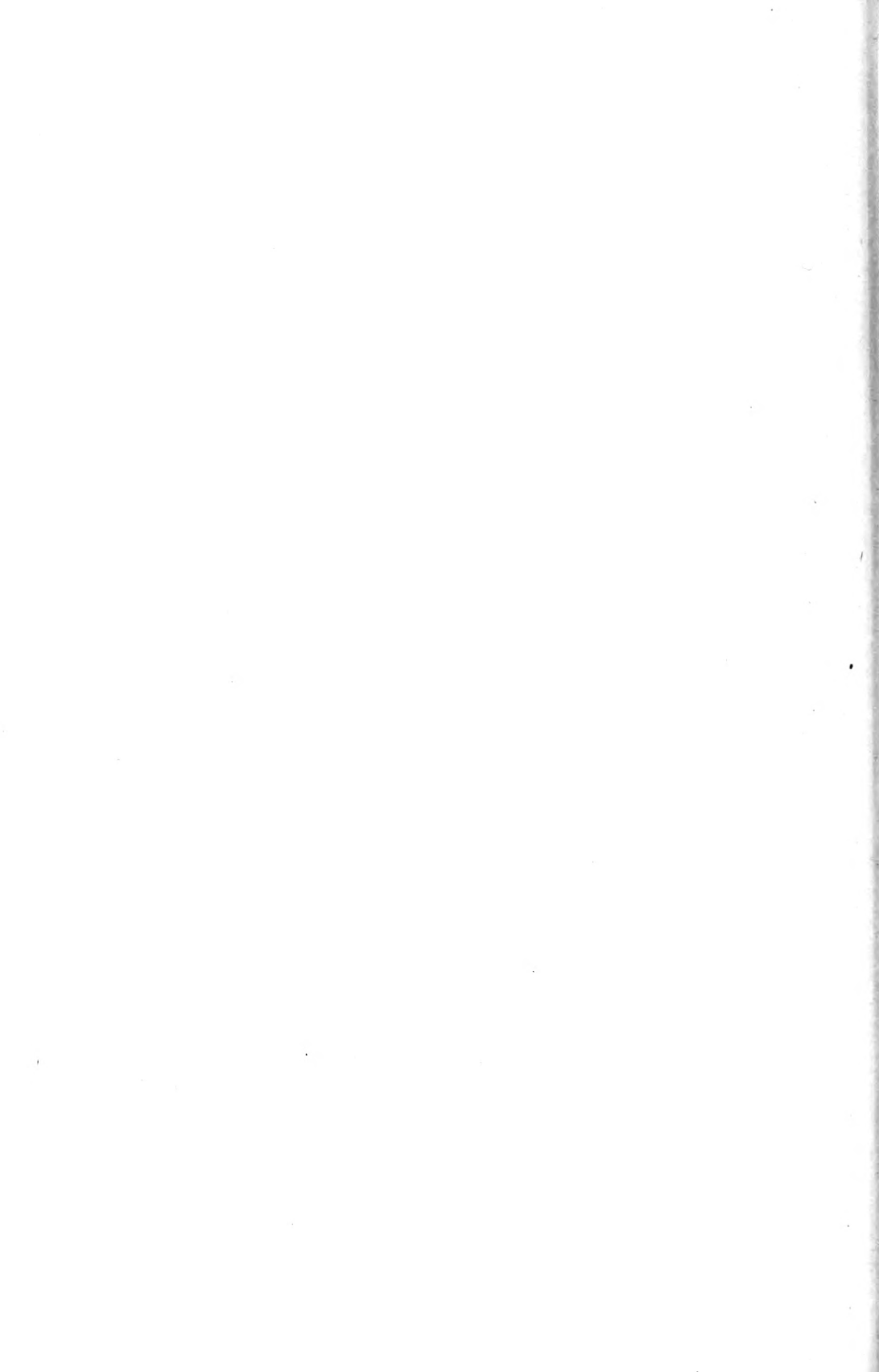
Soluble in HCl with slow but continuous evolution of  $\text{CO}_2$ ; the solution gelatinizes on cooling.

**Nephelite** has much lower double refraction.

**Rhombic carbonates** differ in cleavage and have much higher double refraction.

**Other minerals** are separated by the chemical behavior of cancrinite; the evolution of  $\text{CO}_2$  may be seen in thin sections. Cancrinite also becomes cloudy on heating.

*Cut on line.*



**Chalcedony.**— $\text{SiO}_2 + \text{aq.}$ ,  $\text{H} = 6.0-7.0$ ,  $\text{G} = 2.59-2.64$ .

Orthorhombic. (+).

Cleavage: None.

Habit: Thread-like aggregates, spherulites, concretionary masses, etc.

Elongation: (110):(110), thread-like. (-).

Colorless, yellowish, brownish.

Pleochroism: Wanting.

$\alpha = 1.533$ ,  $\beta = 1.536$ ,  $\gamma = 1.544$ .

$\gamma - \alpha = 0.011$ ,  $\gamma - \beta = 0.008$ ,  $\beta - \alpha = 0.003$ .

$2V = 10^\circ-40^\circ$ .

Chemically like quartz.

**Zeolites** are not thread-like and gelatinize easily with acids.

**Pseudochalcedony** is optically (-) and has smaller double refraction.

**Hydronephelite.**— $\text{Na}_2\text{HAl}_3\text{Si}_3\text{O}_{12} + 3 \text{ aq.}$ ,  $\text{H} = 4.5-6.0$ ,  $\text{G} = 2.26$

Hexagonal (probably). (+).

Cleavage: (1010), poor.

Habit: Rod-like, leafy or rod-like granular aggregates.

Elongation: (1010), short laths. (+).

Colorless, often cloudy.

Pleochroism: Wanting.

Index:  $n = 1.49$  ea.

$\epsilon - \omega = 0.012$ .

Soluble in HCl with formation of jelly.

*Cut on line.*



The mineral is **anisotropic**.

**Parallel** extinction

**Colorless**.

**Index of refraction** is less than  
that of Canada balsam.

**Maximum birefringence** is greater  
than that of quartz.

**Biaxial**.

**BIAXIAL.**

*Cut on line.*





**Cordierite.**— $\text{Mg}_2\text{Al}_4\text{Si}_3\text{O}_{18}$ ,  $H = 7.0-7.5$ ,  $G = 2.59-2.66$ .  
 Orthorhombic.  $(-)$ .  
 Cleavage:  $(010)$ , poor.  
 Habit: Grains, short prisms. Trillings and polysynthetic twins occur.  
 Elongation:  $(110):(110)$ , short laths,  $(-)$ .  
 Orientation:  $b = c$ ,  $c = a$ .  
 Colorless, bluish, yellowish.  
 Pleochroism: Wanting or weak with  $b > c > a$ .  
 $\alpha = 1.535$ ,  $\beta = 1.540$ ,  $\gamma = 1.544$ .  
 $\gamma - \alpha = 0.009$ ,  $\gamma - \beta = 0.004$ ,  $\beta - \alpha = 0.005$ .  
 Dispersion: Weak,  $\rho < \gamma$ .  
 $2E = 63^\circ-150^\circ$ .

When treated with HF gives characteristic prismatic crystals of magnesium fluosilicate.

**Quartz** has higher interference colors, is uniaxial, and  $(+)$ .  
 Chemically different, reactions as above.



**Chalcedony.**— $\text{SiO}_2 + \text{aq.}$ ,  $H = 6.0-7.0$ ,  $G = 2.59-2.64$ .  
 Orthorhombic. (+).  
 Cleavage: None.  
 Habit: Thread-like aggregates, spherulites, concretionary masses, etc.  
 Elongation:  $(110):(1\bar{1}0)$ , thread-like. (-).  
 Orientation:  $c = a$ .  
 Colorless, yellowish, brownish.  
 Pleochroism: Wanting.  
 $\alpha = 1.533$ ,  $\beta = 1.536$ ,  $\gamma = 1.544$ .  
 $\gamma - \alpha = 0.011$ ,  $\gamma - \beta = 0.008$ ,  $\beta - \alpha = 0.003$ .  
 $2V = 10^\circ-40^\circ$ .

Chemically like quartz.

**Zeolites** are not thread-like and gelatinize easily with acids.

**Pseudochalcedony** is optically (-) and has smaller double refraction.

**Natrolite.**— $\text{Na}_2\text{Al}_2\text{Si}_3\text{O}_{10} + 2\text{aq.}$ ,  $H = 5.0-5.5$ ,  $G = 2.17-2.25$ .  
 Orthorhombic. (+).  
 Cleavage:  $(110)$ , good.  $(110):(1\bar{1}0) = 88^\circ 45.5'$ .  
 Habit: Needles, rods  
 Elongation:  $(110):(110)$ , narrow lath-shaped. (+).  
 Orientation:  $a = a$ ,  $c = c$ .  
 Colorless, yellowish.  
 Pleochroism: Wanting.  
 $\alpha = 1.477$ ,  $\beta = 1.480$ ,  $\gamma = 1.489$ .  
 $\gamma - \alpha = 0.012$ ,  $\gamma - \beta = 0.009$ ,  $\beta - \alpha = 0.003$ .  
 Dispersion:  $\rho < \nu$ .  
 $2V = 60^\circ-62.5^\circ$ .

Like all zeolites, natrolite gelatinizes easily with acids.

**Scolecite** has (-) elongation.

**Serpentine.**— $\text{H}_4(\text{Mg}, \text{Fe})_3\text{Si}_2\text{O}_9$ ,  $H = 3.0-4.0$ ,  $G = 2.5-2.7$ .  
 Orthorhombic, probably. (+).  
 Cleavage: Generally none. Antigorite cleaves in thin leaves.  
 Habit: Aggregates, threads, leaves.  
 Elongation:  $(110):(110)$ , thread-like. (+).  
 Orientation:  $b = a$ ,  $c = c$ .  
 Green, colorless, yellowish.  
 Pleochroism: Very weak or wanting.  
 Index:  $n = 1.54$  ca.  
 $\gamma - \alpha = 0.013$ .  
 Dispersion:  $\rho > \nu$ .  
 $2E = 16^\circ-50^\circ$ .

Soluble in boiling HCl with separation of gelatinous silica.

**Pennine** is ( $\pm$ ), has lower birefringence, and is pleochroic.

Chemical test for Al is often the only sure separation.

*Cut on line.*



Thomsonite.— $(\text{CaNa}_2)_2\text{Al}_4\text{Si}_4\text{O}_{16} + 5 \text{ aq.}$ ,  $n = 5.0-5.5$ ,

$G = 2.3-2.4$ .

Orthorhombic. (+).

Cleavage: (010), (100), good.

Habit: Plates, leaves.

Elongation: (110):(1 $\bar{1}$ 0), lath-shaped. ( $\pm$ ).

Orientation:  $a = a$ ,  $b = c$ .

Colorless.

Pleochroism: Wanting.

$\alpha = 1.497$ ,  $\beta = 1.503$ ,  $\gamma = 1.525$ .

$\gamma - \alpha = 0.028$ ,  $\gamma - \beta = 0.022$ ,  $\beta - \alpha = 0.006$ .

Dispersion:  $\rho < \nu$ , strong.

$2E = 87^\circ$  ca.

Gelatinizes with HCl as do all zeolites.

**Prehnite** and **datolite** have higher indices and are attacked with difficulty by acids.

**Other zeolites** have lower birefringence.

*Cut on line.*



The mineral is **anisotropic**.

**Parallel** extinction.

**Colorless**.

**Index of refraction** is **greater** than  
that of Canada balsam.

INDEX > CANADA BALSAM.

*Cut on line.*





The mineral is **anisotropic**.

**Parallel extinction.**

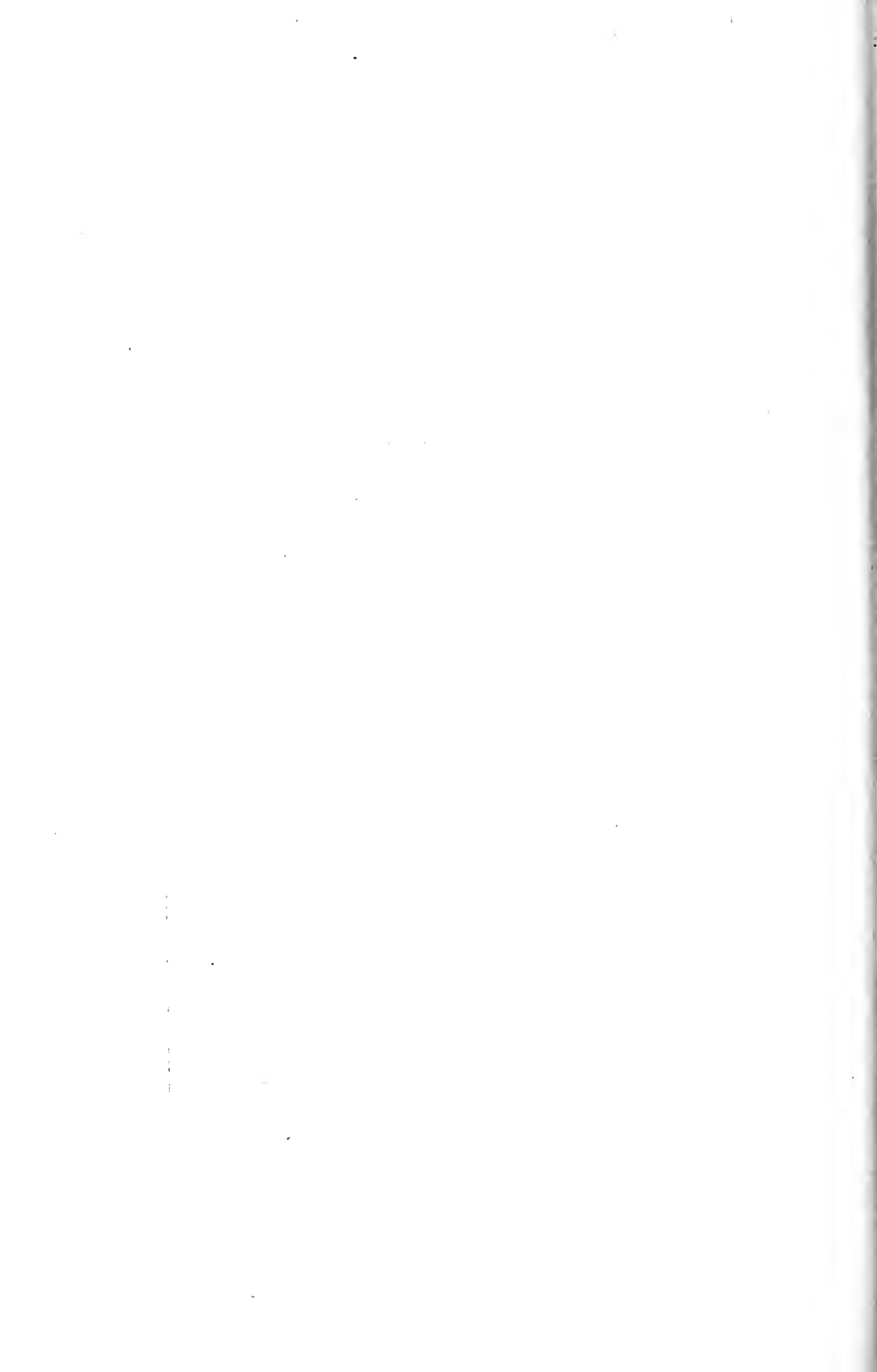
**Colorless.**

**Index of refraction is greater** than  
that of Canada balsam.

**Maximum birefringence is less**  
than that of quartz.

BIREFRINGENCE < QUARTZ.

*Cut on line.*



The mineral is **anisotropic**.

**Parallel extinction.**

**Colorless.**

**Index of refraction** is greater than  
that of Canada balsam.

**Maximum birefringence** is less  
than that of quartz.

**Uniaxial.**



**Eucolite.**—Ca, Fe, Mn, Zr, Na silicate.  $H=5.5-6.5$ ,  $G=3.05$ .

Hexagonal. (-).

Cleavage: (0001) distinct.

Habit: Grains.

Elongation: (0001), short lath-shaped. (+).

Reddish, yellowish, brownish, colorless.

Pleochroism:  $O > E$ . Weak or wanting.

$\omega=1.621$ ,  $\epsilon=1.618$ .

$\omega - \epsilon = 0.003$ .

Often anomalous biaxial character with  $2E$  as high as  $50^\circ$ .

Gelatinizes with HCl, which diluted gives reaction for Zr.

Garnets have much higher indices and are isotropic unless with anomalous double refraction.

Tourmaline has stronger double refraction.

Eudialyte is optically (+), elongation is (-), and indices and birefringence are lower.

**Apatite.**— $\text{CaF} \cdot \text{Ca}_4(\text{PO}_4)_3$  and  $\text{CaCl} \cdot \text{Ca}_4(\text{PO}_4)_3$ ,  $H=5.0$ ,  $G=3.10-3.22$ .

Hexagonal. (-).

Cleavage: (0001), (10 $\bar{1}$ 0), poor; long prisms often show cross fractures.

Habit: Long prisms, rounded grains, granular aggregates.

Elongation: (1010):(0110), lath-shaped. (-).

Colorless, violet, brownish, reddish, gray.

Absorption:  $E > O$  in colored crystals.

$\omega=1.638$ ,  $\epsilon=1.634$ .

$\omega - \epsilon = 0.004$ .

Anomalous biaxial character in large individuals only.

Easily soluble in  $\text{H}_2\text{SO}_4$ , yellow precipitate with ammonium molybdate. Easily soluble in  $\text{HNO}_3$ .

Vesuvianite, melilite, gehlenite, zoisite, and tourmaline are either not soluble or have different crystal form or color.

Tourmaline has  $O > E$ , while colored apatite has  $E > O$ .

**Melilite.**—Ca, Mg, Fe, Al silicate,  $H=5.0$ ,  $G=2.9-3.1$ .

Tetragonal. ( $\mp$ ).

Cleavage: (001):(110), poor; only basal cleavage generally seen in thin sections, and this occurs as a single cleft exactly in the center of the lath-shaped section.

Habit: Plates, short prisms.

Elongation: (001), laths. ( $\pm$ ).

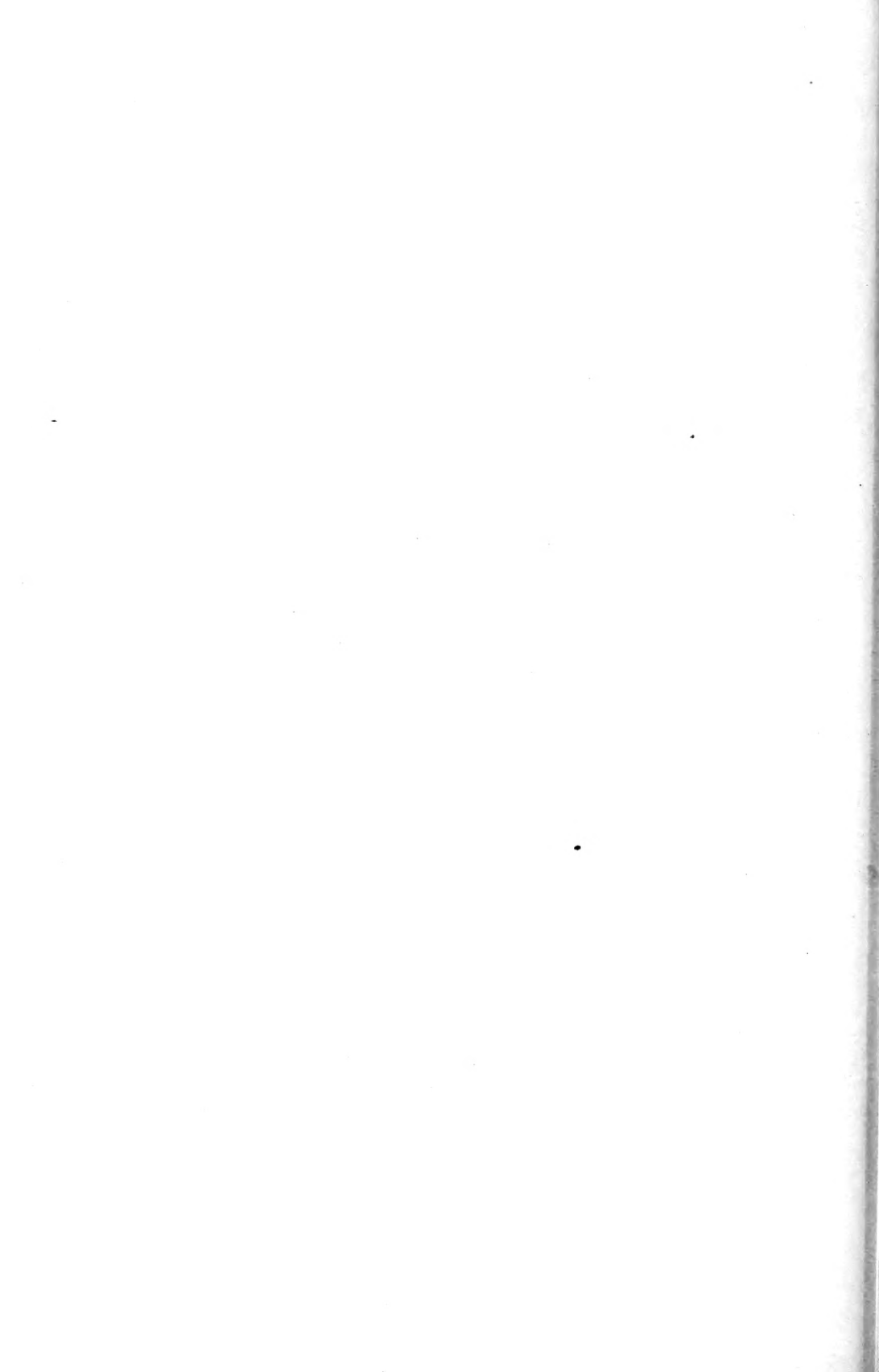
Colorless, yellowish.

Pleochroism: None in colorless melilite; when yellow  $E$ =dark yellow,  $O$ =light yellow.

$\omega=1.634$ ,  $\epsilon=1.629$ .

$\omega - \epsilon = 0.005$ ; often unusual indigo-blue interference colors.

Cut on line.



Gelatinizes easily with HCl. "Peg" structure is characteristic.

Vesuvianite and zoisite are insoluble in acids.

Gehlenite has not the unusual interference colors.

**Nephelite.**— $\text{NaAlSiO}_4$ ,  $H = 5.5\text{--}6.0$ ,  $G = 2.55\text{--}2.61$ .

Hexagonal. (—).

Cleavage: (0001), (10 $\bar{1}$ 0), distinct.

Habit: Short prisms, square sections, and grains.

Elongation: (10 $\bar{1}$ 0), rectangular, quadratic. (—).

Orientation:  $c = a$ .

Colorless.

Pleochroism: Wanting.

$\omega = 1.539\text{--}1.542$ ,  $\epsilon = 1.532\text{--}1.542$ .

$\omega - \epsilon = 0.005$ .

Sometimes has anomalous small 2E.

Gelatinizes easily with HCl and is readily stained.

Sodalite minerals have lower indices and no double refraction.

Apatite, gehlenite, and melilite have higher indices.

Scapolites have higher indices and higher double refraction.

Different cleavage.

Sanidine and orthoclase have lower double refraction and are unaffected by HCl. They are also biaxial.

**Vesuvianite.**— $\text{Al}_2(\text{SiO}_4)_3\text{Ca}_6(\text{AlOH})$ ,  $H = 6.5$ ,  $G = 3.35\text{--}3.47$ .

Tetragonal. (—, rarely +).

Cleavage: (110), (100), poor.

Habit: Short prisms, grains, dull masses.

Elongation: (110):(110), prismatic. (±).

Colorless, yellowish, greenish, reddish, brownish, blue.

Pleochroism: Weak to unnoticeable.

$\omega = 1.705\text{--}1.732$ ,  $\epsilon = 1.701\text{--}1.726$ .

$\omega - \epsilon = 0.006\text{--}0.001$ , often abnormal colors.

Anomalous biaxial character.

Insoluble in acids unless fused to glass.

Occurs in metamorphic rocks.

Zoisite has the high indices and weak double refraction found in vesuvianite. The optic angle of zoisite often falls as low as 0°, and vesuvianite has often anomalous double refraction with very variable axial angle. Zoisite, however, has good pinacoidal cleavage.

Gehlenite gelatinizes easily with HCl.

Andalusite always has a larger axial angle.

*Cut on line.*





Gehlenite.— $\text{Ca}_3(\text{AlO})_2\text{Si}_2\text{O}_8$ ,  $H=5.5-6.0$ ,  $G=2.9-3.1$ .

Tetragonal. (—).

Cleavage: (001), (110), poor.

Habit: Thick plates, cubic and rounded grains, cloudy masses.

Colorless.

Pleochroism: None.

$\omega=1.663$ ,  $\epsilon=1.658$ .

$\omega-\epsilon=0.006$ .

Gelatinizes easily with HCl.

Apatite has cross-parting and different crystal form.

Vesuvianite has lower double refraction and is insoluble in acids.

Melilite has lower double refraction and different micro-structure.

Corundum.— $\text{Al}_2\text{O}_3$ ,  $H=9.0$ ,  $G=3.9-4.10$ .

Hexagonal. (—).

Cleavage: A poor parting (10 $\bar{1}$ 1), (0001).

Habit: Plates, grains, prisms. Twins (10 $\bar{1}$ 1) occur.

Elongation: (0001), lath-shaped. (+).

Colorless, blue, light red.

Pleochroism:  $O$ =blue, red;  $E$ =sea-green, yellow, or greenish yellow; seen only in deeply-colored corundum.

$\omega=1.769$ ,  $\epsilon=1.760$ .

$\omega-\epsilon=0.009$ .

Insoluble in acids or fused soda.

Other minerals which resemble it are separated by the high indices, negative character, uniaxial figure, etc., of corundum.

*Cut on line.*



**Garnet.**—Ca, Mg, Fe, Mn, Al, Cr silicate,  $H=7.0-7.5$ ,  $G=3.4-4.3$ .  
 Isometric.  
 Cleavage: Wanting; shows strong, irregular cracks.  
 Habit: (110), quadratic, hexagonal, or octagonal outlines. or irregular rounded grains.  
 Colorless, red, brown, green, yellow.  
 Index: 1.74–1.86.  
 Anomalous double refraction common in most varieties.  
 Zonal structure common.  
 Insoluble in acids.  
**Perovskite** has different crystal form.

**Perovskite.**— $\text{CaTiO}_3$ ,  $H=5.5$ ,  $G=4.02-4.04$ .  
 Isometric.  
 Cleavage in large individuals, (100), distinct. Not seen in thin sections.  
 Habit: Octahedrons, (111); sharp, sometimes rounded cubes.  
 Grayish white, violet-gray, brownish to red-brown, rarely greenish gray.  
 Index:  $n_{na}=2.38$ .  
 Anomalous double refraction in large individuals; often not seen under the microscope.  
**Other anisotropic minerals** show higher double refraction, interference figures, etc.

**Eudialyte.**—Ca, Fe, Mn, Zr, Na silicate,  $H=5.5-6.5$ ,  $G=2.92$ .  
 Hexagonal. (+).  
 Cleavage: (0001) distinct.  
 Habit: Rhombs, thick plates.  
 Elongation: 0001), short lath-shaped. (-).  
 Reddish, yellowish, brownish, colorless.  
 Pleochroism:  $O > E$ , weak or wanting.  
 $\omega=1.606-1.611$ ,  $\epsilon=1.610-1.613$ .  
 $\epsilon - \omega = 0.002$ .  
 Often anomalous biaxial character,  $2E$  up to  $50^\circ$ .  
 Gelatinizes with HCl, which, when diluted, gives reaction for Zr.  
**Garnets** have much higher indices and are isotropic unless with anomalous double refraction.  
**Tourmaline** has stronger double refraction.  
**Eucolite** is optically (-), elongation is (+), and indices and double refraction are higher.

**Quartz.**— $\text{SiO}_2$ ,  $H=7.0$ ,  $G=2.65$ .  
 Hexagonal. (+).  
 Cleavage: Irregular cracks.

*Cut on line.*



Habit: Dihexahedrons, grains; irregular, allotriomorphic.

Colorless.

Pleochroism: None.

$\omega = 1.544$ ,  $\varepsilon = 1.553$ .

$\varepsilon - \omega = 0.009$ .

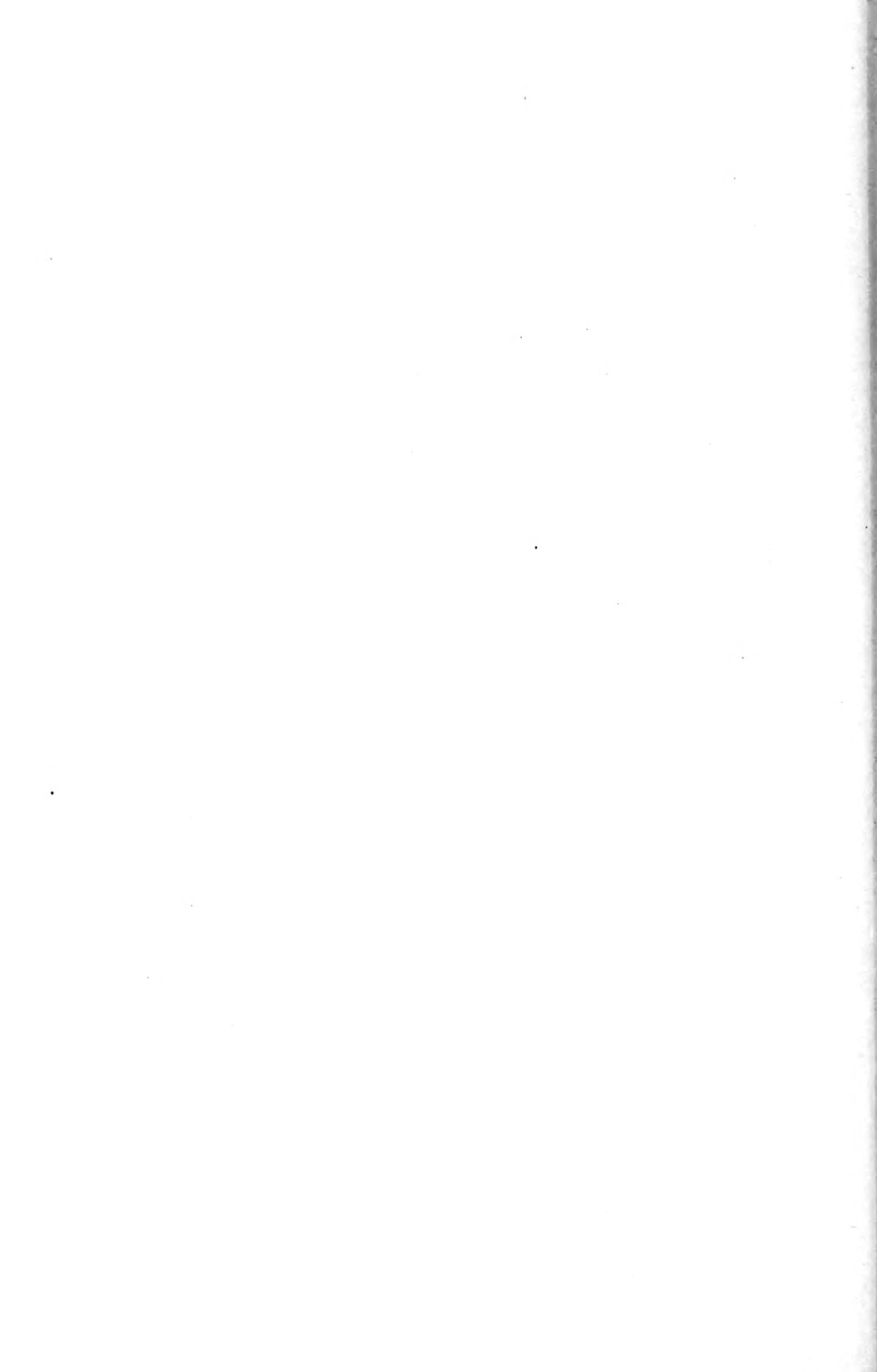
$2E = 12^\circ - 18^\circ$ , rarely to  $24^\circ$ . Extinction often undulatory; optical anomalies common.

Unaffected by acids.

**Other minerals:** The low indices and double refraction of quartz combined with its lack of color, lack of cleavage, freshness, insolubility in acids, etc. separate it from most of the other minerals.

**Cordierite** is biaxial,  $(-)$ , and when treated with HF gives characteristic prismatic crystals of magnesium fluosilicate.

*Cut on line.*



The mineral is **anisotropic**.

**Parallel extinction.**

**Colorless.**

**Index of refraction** is **greater** than  
that of Canada balsam.

**Maximum birefringence** is **less**  
than that of quartz.

**Biaxial.**

BIAXIAL

*Cut on line.*





**Lepidolite.**— $\text{Al}(\text{SiO})_3\text{Al}_2\text{KLiH} + \text{Al}(\text{Si}_3\text{O}_8)_3\text{K}_3\text{Li}_3(\text{AlF}_2)_3$ ,  $H = 2.5-4.0$ ,  $G = 2.8-2.9$ .

Monoclinic. (—).

Cleavage: (001), good.

Habit: Leaves, leafy aggregates.

Elongation: At right angles to (001), lath-shaped. (+)

Orientation:  $b = c$ ,  $a = +0^\circ$  to  $+2^\circ$  or rarely

$b = b$ ,  $c: a = +0^\circ$  to  $+2^\circ$ .

Colorless, reddish.

Pleochroism: Weak or none.

$\alpha = ( )$ ,  $\beta = 1.598$ ,  $\gamma = 1.605$ .

$\gamma - \beta = 0.007$ .

Dispersion: Weak,  $\rho \geq v$ .

$2E = 32^\circ-84^\circ$ .

One of the mica group.

Gives Li flame in BB. Attacked but not completely decomposed by acids. After fusion gelatinizes with acid.

**Muscovite** and **paragonite** do not give Li flame.

**Oligoclase.**— $\text{Ab}_6\text{An}_1$  to  $\text{Ab}_2\text{An}_1$ ,  $H = 6.0-6.5$ ,  $G = 2.64-2.66$ .

Triclinic. (—).

Cleavage: (001), (010), good. (001):(010) =  $86^\circ 32'$ .

Habit: Plates, prisms, grains.

Elongation: (001):(010), (110):(1 $\bar{1}$ 0).

Orientation:  $A_{001} = +1^\circ$ ,  $A_{010} = +4.5^\circ$ .

Colorless.

Pleochroism: Wanting.

$\alpha = 1.540$ ,  $\beta = 1.544$ ,  $\gamma = 1.547$ .

$\gamma - \alpha = 0.007$ ,  $\gamma - \beta = 0.003$ ,  $\beta - \alpha = 0.004$

Dispersion:  $\rho > v$ .

$2V = 90^\circ-98^\circ$ .

Insoluble in acids.

**Other feldspars.** See Part II.

**Cordierite.**— $\text{Mg}_2\text{Al}_4\text{Si}_5\text{O}_{18}$ ,  $H = 7.0-7.5$ ,  $G = 2.59-2.66$ .

Orthorhombic. (—).

Cleavage: (010), poor.

Habit: Grains, short prisms. Trillings and polysynthetic twins occur.

Elongation: (110), (1 $\bar{1}$ 0), short laths. (—).

Orientation:  $b = c$ ,  $c = a$ .

Colorless, bluish, yellowish.

Pleochroism: Wanting or weak with  $b > c > a$

$\alpha = 1.535$ ,  $\beta = 1.540$ ,  $\gamma = 1.544$ .

$\gamma - \alpha = 0.009$ ,  $\gamma - \beta = 0.004$ ,  $\beta - \alpha = 0.005$

Dispersion: Weak,  $\rho < v$ .

$2E = 63^\circ-150^\circ$ .

*Cut on line.*



When treated with HF gives characteristic prismatic crystals of magnesium fluosilicate.

Quartz has higher interference colors, is uniaxial, and (+).

Chemically different, reactions as above.

**Andalusite.**— $\text{Al}_2\text{SiO}_5$ ,  $H=7.5$ ,  $G=3.10-3.20$ .

Orthorhombic. (—).

Cleavage: (110), good.  $(110):(1\bar{1}0)=89^\circ 12'$ .

Habit: Prisms, grains.

Elongation:  $(110):(1\bar{1}0)$ , short laths. (—).

Orientation:  $a=c$ ,  $c=a$ .

Colorless, reddish.

Pleochroism:  $a$ =rose,  $b=c$ =colorless to light green.

$\alpha=1.632$ ,  $\beta=1.638$ ,  $\gamma=1.643$ .

$\gamma-\alpha=0.011$ ,  $\gamma-\beta=0.005$ ,  $\beta-\alpha=0.006$ .

$2V=84^\circ-85^\circ$ .

Insoluble even in HF.

Sillimanite is (+), has higher double refraction, and (100) cleavage.

Topaz has (001) cleavage and is (+).

Scapolites have higher double refraction in longitudinal sections and are uniaxial.

Zoisite has (010) and (100) cleavage, and the acute bisectrix is at right angles to (100). (+).  $2V=0^\circ-60^\circ$ .

Thulite has similar pleochroism, but  $2V=0^\circ-40^\circ$ . (+).

Orthoclase has lower indices.

Prismatine and cornerupine have smaller axial angles.

*Cut on line.*



**Andesine.**— $\text{Ab}_3\text{An}_2$  to  $\text{Ab}_4\text{An}_3$ ,  $H=6.0-6.5$ ,  $G=2.66-2.69$ .

Triclinic. (+).

Cleavage: (001), (010), good. (001):(010) =  $86^\circ 14'$ .

Habit: Plates, prisms, grains.

Elongation: (001):(010), (110):(1 $\bar{1}$ 0), laths, plates

Orientation:  $A_{001} = -2^\circ$ ,  $A_{010} = -8^\circ$ .

Colorless.

Pleochroism: None.

$\alpha=1.549$ ,  $\beta=1.553$ ,  $\gamma=1.555$ .

$\gamma-\alpha=0.006$ ,  $\gamma-\beta=0.002$ ,  $\beta-\alpha=0.004$ .

Dispersion:  $\rho < \nu$ .

$2V=90^\circ-80^\circ$ .

Insoluble in acids.

(See Part II, for special determinations.)

**Clinozoisite.**— $\text{Al}(\text{SiO}_4)_3(\text{Al}, \text{Fe})_2\text{Ca} \cdot \text{CaOH}$ ,  $H=6.5$ ,  $G=3.3-3.5$ .

Monoclinic. (+).

Cleavage: (001), good; (100), distinct. (001):(100) =  $64^\circ 37'$ .

Habit: Prisms and rods elongated on  $b$ ; grains. Twinning (100).

Elongation: (001):(100), lath-shaped. ( $\pm$ ).

Orientation:  $b=\mathbf{b}$ ,  $c:\mathbf{a} = -3^\circ$ .

Colorless, reddish.

Pleochroism: Weak.

$\alpha=1.716$ ,  $\beta=1.718$ ,  $\gamma=1.724$ .

$\gamma-\alpha=0.008$ ,  $\gamma-\beta=0.006$ ,  $\beta-\alpha=0.002$ .

Dispersion: Strong,  $\rho < \nu$ .

$2V=80^\circ-90^\circ$ .

An iron-poor or iron-free epidote. Pistacite is the iron-rich epidote.

Abnormal interference color. Strong dispersion of the bisectrices.

Insoluble in HCl.

Zoisite has parallel extinction, smaller  $2V$ .

**Enstatite.**— $(\text{Mg}, \text{Fe})_2\text{Si}_2\text{O}_6$ ,  $H=5.0-6.0$ ,  $G=3.1$ .

Orthorhombic. (+).

Cleavage: (110), good; (010), distinct; (100), good. (110):(1 $\bar{1}$ 0) =  $91^\circ 40'$ .

Habit: Prismatic, cloudy masses.

Elongation: (110):(1 $\bar{1}$ 0), lath-shaped. (+).

Orientation:  $b=\mathbf{a}$ ,  $c=\mathbf{c}$ .

Colorless.

Pleochroism: Wanting.

$\alpha=1.656$ ,  $\beta=1.659$ ,  $\gamma=1.665$ .

$\gamma-\alpha=0.009$ ,  $\gamma-\beta=0.006$ ,  $\beta-\alpha=0.003$ .

Dispersion:  $\rho < \nu$ .

$2E=135^\circ$  ca.



Insoluble in acids.

**Monoclinic pyroxenes** have higher double refraction and inclined extinction. In basal sections the monoclinic pyroxenes show the emergence of an axis, while the orthorhombic pyroxenes show the emergence of a positive bisectrix.

**Ægirite** is pleochroic, has higher double refraction, and (−) elongation.

**Bastite** cleavage flakes along the best pinacoidal cleavage, show the emergence of a negative bisectrix with small axial angle; enstatite shows the emergence of the optic normal.

**Diallage** in similar flakes shows the emergence of an optic axis.

**Bronzite.**— $(\text{Mg, Fe})_2\text{Si}_2\text{O}_6$ ,  $H=5.0-6.0$ ,  $G=3.29$ .

Orthorhombic. (+).

Cleavage: (010), distinct; (100), good; (110), good. (110):(1 $\bar{1}$ 0) =  $91^\circ 40'$ .

Habit: Prismatic, cloudy. Geniculated and star-shaped twins, rare.

Elongation: (110):(1 $\bar{1}$ 0), lath-shaped. (+).

Orientation:  $b = a$ ,  $c = t$ .

Colorless, yellowish, reddish.

Pleochroism: Weak,  $t$ =greenish,  $a$ =reddish yellow,  $b$ =reddish brown.

$\alpha = 1.665$ ,  $\beta = 1.669$ ,  $\gamma = 1.674$ .

$\gamma - \alpha = 0.009$ ,  $\gamma - \beta = 0.005$ ,  $\beta - \alpha = 0.004$ .

Dispersion:  $\rho < \nu$ .

$2E = 106^\circ$  ca.

**Hypersthene** has same pleochroism, strong, and is (−).

**Monoclinic pyroxenes.** See enstatite, just preceding.

**Zoisite.**— $\text{HCa}_2\text{Al}_3\text{Si}_3\text{O}_{13}$ ,  $H=6.0-6.5$ ,  $G=3.25-3.37$ .

Orthorhombic. (+).

Cleavage: (010), good; (100), distinct.

Habit: Rods, leaves.

Elongation: (110):(1 $\bar{1}$ 0), short laths. ( $\pm$ ).

Orientation:  $a = t$ ,  $c = a$ , or  $a = t$ ,  $b = a$ .

Colorless.

Pleochroism: None in thin sections.

$\alpha = 1.698$ ,  $\beta = 1.699$ ,  $\gamma = 1.707$ .

$\gamma - \alpha = 0.009$ ,  $\gamma - \beta = 0.008$ ,  $\beta - \alpha = 0.001$ .

Dispersion: Strong  $\rho < \nu$ ,  $\rho > \nu$ .

$2V = 0^\circ-60^\circ$ .

Insoluble in acids.

Abnormal interference colors.

Cut on line.





**Pistacite**, with weak double refraction, is similar when the axial plane is at right angles to the cleavage.

**Vesuvianite** has poor cleavage.

**Melilite** gelatinizes with acids.

**Topaz.**—  $\text{Al}_2\text{SiO}_4(\text{F}, \text{OH})_2$ ,  $H = 8.0$ ,  $G = 3.533\text{--}3.574$ .

Orthorhombic. (+).

Cleavage: (001), good.

Habit: Short prisms, grains, rods.

Elongation: (001). (—).

Orientation:  $a = a$ ,  $c = c$ .

Colorless.

Pleochroism: None in thin sections.

$\alpha = 1.619$ ,  $\beta = 1.622$ ,  $\gamma = 1.628$ .

$\gamma - \alpha = 0.010$ ,  $\gamma - \beta = 0.006$ ,  $\beta - \alpha = 0.003$ .

Dispersion:  $\rho > \nu$ .

$2E = 71^\circ\text{--}129^\circ$ .

Occurs in schists, gneisses, and in cavities of volcanic rocks.

Insoluble in acids.

**Quartz** has lower indices and no cleavage, basal sections give uniaxial interference figures.

**Andalusite** is (—), has good (110) cleavage, and different orientation.

**Sillimanite** and **prismatine** have different orientation.

*Cut on line.*



The mineral is anisotropic.

Parallel extinction.

Colorless.

Index of refraction is greater than  
that of Canada balsam.

Maximum birefringence is greater  
than that of quartz.

BIREFRINGENCE > QUARTZ.

*Cut on line.*



The mineral is anisotropic.

Parallel extinction.

Colorless.

Index of refraction is greater than  
that of Canada balsam.

Maximum birefringence is greater  
than that of quartz.

Uniaxial.

UNIAXIAL.

*Cut on line.*



**Corundum.**— $\text{Al}_2\text{O}_3$ ,  $H=9.0$ ,  $G=3.9-4.10$ .

Hexagonal. (—).

Cleavage: A poor parting,  $(10\bar{1}1)$ ,  $(0001)$ .

Habit: Plates, grains, prisms. Twins  $(10\bar{1}1)$  occur.

Elongation:  $(0001)$ , lath-shaped. (+).

Colorless, blue, light red.

Pleochroism:  $O$ =blue, red;  $E$ =sea-green, yellow, or greenish yellow. Only seen in deeply colored corundum.

$\omega=1.769$ ,  $\varepsilon=1.760$ .

$\omega-\varepsilon=0.009$ .

Insoluble in acids or fused soda.

Other minerals which resemble it are separated by the high indices, negative character, uniaxial figure, etc., of corundum.

**Dipyr.**—Aluminium, sodium, calcium silicate,  $H=5.0-6.0$ ,  $G=\pm 2.6$ .

Tetragonal. (—).

Cleavage:  $(100)$ , good;  $(110)$ , poor.

Habit: Rods, prisms, grains.

Elongation:  $(110):(1\bar{1}0)$ , lath-shaped. (—).

Colorless.

Pleochroism: None.

$\omega=1.555$ ,  $\varepsilon=1.542$ .

$\omega-\varepsilon=0.013$ .

Optical anomalies showing opening of interference cross, rare.

Dipyr occurs in contact metamorphosed limestones and schists.

It is a scapolite.

**Feldspar**, **cordierite**, and **zoisite** have lower double refraction, are biaxial, and have different cleavage.

**Quartz** is (+), has no cleavage, and has lower double refraction.

**Prehenite** and light-colored **micas** with apparent uniaxial character are characterized by their cleavage.

**Andalusite** has lower double refraction and is biaxial.

**Mizzonite.**—Like dipyr chemically, etc.

Tetragonal. (—).

Cleavage:  $(100)$ , good;  $(110)$ , poor.

Habit: Rods, prisms, grains.

Elongation:  $(110):(1\bar{1}0)$ , lath-shaped. (—).

Colorless.

Pleochroism: None.

$\omega=1.558$ ,  $\varepsilon=1.543$ .

$\omega-\varepsilon=0.015$ .

Optical anomalies rare, showing an opening of the interference cross. It is never primary in eruptive rocks, but occurs

Cut on line.





as an alteration product of feldspars. Occurs in crystalline schists and gneisses.

**Other minerals.** See Dipyr above. This is also a scapolite.

**Meionite.**—Like dipyr chemically, etc., G = 2.735.

Tetragonal. (—).

Cleavage: (100), good; (110), poor.

Habit: Rods, prisms, grains.

Elongation: (110):(110), lath-shaped. (—).

Colorless.

Pleochroism: Wanting.

$\omega = 1.595$ ,  $\epsilon = 1.560$ .

$\omega - \epsilon = 0.035$ . Varies, sometimes 0.019.

Optical anomalies rare, showing opening of interference cross.

Never occurs primary in eruptive rocks, but as an alteration product of feldspars. Occurs in crystalline schists and gneisses.

**Other minerals.** See Dipyr above. This is also a scapolite.

**Phlogopite.**—Fe poor mica, H = 2.5–3.0, G = 2.85.

Monoclinic. (—).

Cleavage: (001), good.

Habit: Leaves, leafy aggregates.

Elongation: Right angles to (001), lath-shaped. (+).

Orientation:  $b = \mathfrak{b}$ ,  $c: a = 0^\circ$  to  $+7^\circ$ .

Colorless, yellowish, brownish, greenish.

Pleochroism: Weak with  $\epsilon > \mathfrak{b} > a$ .

$\alpha = 1.562$ ,  $\beta = 1.606$ ,  $\gamma = 1.606$ .

$\gamma - \alpha = 0.044$ ,  $\gamma - \beta = 0.0$ ,  $\beta - \alpha = 0.044$ .

Dispersion: Weak with  $\rho < \nu$ .

$2E$  = small to  $0^\circ$ .

**Other minerals** than micas differ in not having such low double refraction in basal, and high double refraction in other sections.

**Chlorite** has lower double refraction.

**Lepidolite** has larger values for  $2E$ .

**Muscovite** is non-pleochroic.

**Biotite** is more strongly pleochroic

**Anatase.**— $\text{TiO}_2$ , H = 5.5–6.0, G = 3.82–3.95.

Tetragonal. (—).

Cleavage: (001):(111), good. (111):(111) =  $43^\circ 24'$ .

Habit: Pyramids, tabular.

Colorless, blue, also yellowish or greenish.

*Cut on line.*



Pleochroism:  $O$  = deep blue, orange-yellow;  $E$  = light blue, light yellow. Weak.

$\omega = 2.562$ ,  $\varepsilon = 2.489$ .

$\omega - \varepsilon = 0.0732$ .

Colorless or yellow portions are usually normal, the blue portions are optically anomalous. They do not fully extinguish, and the interference cross opens.

**Rutile, brookite, pseudobrookite, cassiterite, and zircon** differ in being (+) and by having different form and different cleavage.

**Perovskite** has different form, and the anomalous interference colors are lower than those in anatase.

**Calcite.**— $\text{CaCO}_3$ ,  $H = 3.0$ ,  $G = 2.714$ .

Hexagonal. (—).

Cleavage: (1011), good.  $(1011):(1101) = 74^\circ 55'$ .

Habit: Grains, granular aggregates, threads, rounded aggregates.

Twinning (0112) common.

Colorless, gray, yellowish, brownish.

Absorption:  $O > E$ .

$\omega = 1.658$ ,  $\varepsilon = 1.486$ .

$\omega - \varepsilon = 0.172$ .

Often incloses rhombs of dolomite and magnesite. Readily soluble in cold HCl.

**Aragonite** is biaxial and has different cleavage. See also special tests in Part II.

**Dolomite** twinning (02 $\bar{2}$ 1). Special tests, see Part II.

**Dolomite.**— $\text{MgCaC}_2\text{O}_6$ ,  $H = 3.5-4.0$ ,  $G = 2.85-2.95$ .

Hexagonal. (—).

Cleavage: (1011), good.  $(1011):(1101) = 73^\circ 45'$ .

Habit: Rhombohedrons, granular aggregates. Twins occasionally occur, (02 $\bar{2}$ 1).

Colorless, gray, yellowish, brownish.

Absorption:  $O > E$ , strong.

$\omega = 1.682$ ,  $\varepsilon = 1.503$ .

$\omega - \varepsilon = 0.179$ .

Soluble with difficulty in cold acid; easily in hot.

**Calcite** has lower indices, is soluble in acetic acid, and has (0112), twinning. Chemical differences between calcite, dolomite, and aragonite, see Part II.

**Magnesite.**— $\text{MgCO}_3$ ,  $H = 3.5-4.5$ ,  $G = 2.9-3.1$ .

Hexagonal. (—).

Cleavage: (10 $\bar{1}$ 1), good.  $(10\bar{1}1):(1101) = 72^\circ 40'$ .

Habit: Rhombohedrons, granular aggregates.

Cut on line.



Colorless, yellowish, grayish, brownish.

Absorption:  $O > E$ .

$\omega_{na} = 1.717$ ,  $\varepsilon_{na} = 1.515$ .

$\omega - \varepsilon = 0.202$ .

Cold HCl does not affect magnesite.

Dolomite and calcite are acted upon more readily by acids.

Siderite.—  $\text{FeCO}_3$ ,  $H = 3.5-4.0$ ,  $G = 3.936-3.938$ .

Hexagonal.  $(-)$ .

Cleavage:  $(10\bar{1}1)$ , good.  $(10\bar{1}1):(1101) = 73^\circ$ .

Habit: Rhombohedrons, granular aggregates.

Colorless, yellowish, brownish.

Absorption: Strong  $O > E$ .

$\omega = 1.872$ ,  $\varepsilon = 1.634$ .

$\omega - \varepsilon = 0.238$ .

Soluble in HCl.

Other carbonates separated by chemical means.

*Cut on line.*



Quartz.—  $\text{SiO}_2$ ,  $H = 7.0$ ,  $G = 2.65$ .

Hexagonal. (+).

Cleavage: Irregular cracks.

Habit: Dihexahedrons, grains.

Colorless.

Pleochroism: None.

$\omega = 1.544$ ,  $\varepsilon = 1.553$ .

$\varepsilon - \omega = 0.009$ .

$2E = 12^\circ - 18^\circ$ , rarely to  $24^\circ$ .

Extinction often undulatory; optical anomalies common.

Unaffected by acids.

**Other minerals:** The low indices and double refraction of quartz combined with its lack of color, lack of cleavage, freshness, insolubility in acids, etc., separate it from most of the other minerals.

**Cordierite** is biaxial, (-), and when treated with HF gives characteristic prismatic crystals of magnesium fluosilicate.

Mosandrite. } Ti, Zr, Th, Ce, Y, Al, Fe, Mn, Ca, Mg, Na, K, F silicate,  
Johnstrupite. }  $H = 4.0$  and more,  $G = 3.10 - 3.29$  (Johnst.),  $2.93 - 3.07$ .  
(Mosand.)

Monoclinic. (+).

Cleavage: (100), good.

Habit: Tablets, (100), elongated on  $c$ . Twinning (100) frequent.

Elongation: (100):(010), lath-shaped. (-).

Orientation:  $b = b$ ,  $c : a = 3^\circ$ .

Grayish yellow to colorless.

Pleochroism: Not seen in thin sections.

$\alpha = 1.646$ ,  $\beta = 1.649$ ,  $\gamma = 1.658$ .

$\gamma - \alpha = 0.012$ ,  $\gamma - \beta = 0.009$ ,  $\beta - \alpha = 0.003$ .

Dispersion: Strong,  $\rho > \nu$ .

$2V = 70^\circ$ .  $2E_{na} = 128^\circ 37'$ .

Soluble in HCl with separation of  $\text{SiO}_2$ ; the dark-red solution becomes yellowish on heating and gives off Cl.

**Rinkite** has strong  $\rho < \nu$  dispersion, and the position of the plane of the optic axes is not symmetrical.

Alunite.—  $\text{K}(\text{AlO}_2\text{H}_2)_3(\text{SO}_4)_2$ ,  $H = 3.5 - 4.0$ ,  $G = 2.6 - 2.8$ .

Hexagonal. (+).

Cleavage: (0001), good.

Habit: Rhombohedrons, plates, grains.

Colorless.

Pleochroism: Wanting.

$\omega = 1.572$ ,  $\varepsilon = 1.592$ .

$\varepsilon - \omega = 0.020$ .

Insoluble in HCl, powder slowly soluble in  $\text{H}_2\text{SO}_4$ .

**Quartz** has no cleavage, weaker double refraction, and is not affected by  $\text{H}_2\text{SO}_4$ .

Cut on line.





**Brucite.**—  $\text{MgO} \cdot \text{H}_2\text{O}$ ,  $H = 2$ ,  $G = 2.38-2.4$ .  
 Hexagonal. (+).  
 Cleavage: (0001), good  
 Habit: Thin plates.  
 Elongation: (0001), lath-shaped. (-).  
 Orientation:  $c = \epsilon$ .  
 Colorless.  
 Pleochroism: None.  
 $\omega = 1.560$ ,  $\epsilon = 1.581$ .  
 $\epsilon - \omega = 0.021$ .  
 The isochromatic curves are often elliptical. Anomalous biaxial character not rare.  
 Soluble in acids without effervescing.  
**Muscovite** and **talc** are (-), insoluble in acids and have greatest ease of vibration perpendicular to cleavage; in brucite the greatest ease is parallel to it.  
**Hydromagnesite** is less strongly doubly refracting, effervesces in HCl.

**Leucoxene.**—An alteration product of ilmenite.  
 Habit: Granular; fibrous at right angles to the ilmenite crystal.  
 Yellowish to nearly opaque. By incident light it is white, yellowish, or brownish.  
 Index: High.  
 Birefringence: Strong, when transparent enough to observe.  
**Other minerals** differ in the mode of occurrence, leucoxene being associated with ilmenite.

**Zircon.**—  $\text{ZrSiO}_4$ ,  $H = 7.5$ ,  $G = 4.2-4.86$ .  
 Tetragonal. (+).  
 Cleavage: (110), good. (100), poor.  
 Habit: Prisms, grains, rarely pyramids.  
 Elongation: (110):(110), prismatic. (+).  
 Colorless, seldom yellowish to reddish.  
 Pleochroism: Weak, not generally observable in thin sections.  
 $\omega = 1.931$ ,  $\epsilon = 1.993$ .  
 $\epsilon - \omega = 0.0443-0.0618$ .  
 Insoluble in acids, except the powder in hot, concentrated  $\text{H}_2\text{SO}_4$ .  
**Cassiterite** has higher double refraction and different chemical reactions.  
**Xenotime** is softer and has lower indices of refraction.

**Hussakite.**—  $3\text{P}_2\text{O}_5 \cdot \text{SO}_3 \cdot 3\text{R}_2\text{O}_3$ , where R is Y, Er, Ga,  $H = 5.0$ ,  $G = 4.587$ .  
 Tetragonal. (+).  
 Cleavage: (110), good.  
 Habit: Pyramids, prisms, grains.

Cut on line.



Elongation: (110):(1 $\bar{1}$ 0), prismatic. (+).

Colorless, yellowish, brownish.

$\omega = 1.717-1.724$ ,  $\varepsilon = 1.8113-1.8196$ .

$\varepsilon - \omega = 0.0948$ .

Insoluble in acids.

The  $\text{SO}_3$  free mineral xenotime may be decomposed hussakite, if so the name xenotime has priority.

**Zircon** has lower double refraction and contains neither  $\text{P}_2\text{O}_5$  nor Y.

**Cassiterite** has higher indices and neither  $\text{P}_2\text{O}_5$  nor Y.

**Cassiterite.**— $\text{SnO}_2$ , H=6.0-7.0, G=6.8-7.1.

Tetragonal. (+).

Cleavage: (110), poor; (100), distinct.

Habit: Grains, prisms, rods, pyramids, twins.

Elongation: (110):(110), prismatic. (+).

Yellowish, brownish, colorless.

Pleochroism: Very weak, generally not observable in thin sections.

$\omega = 1.997$ ,  $\varepsilon = 2.093$ .

$\varepsilon - \omega = 0.096$ .

Optical anomalies, rare and weak.

Insoluble in acids.

**Rutile** has higher double refraction and better cleavage.

**Anatase** is (-).

**Brookite** and **pseudobrookite** are biaxial.

**Perovskite** and **zircon** and all the above differ in chemical reactions and in having lower specific gravities than **cassiterite**.

*Cut on line.*



The mineral is **anisotropic**.

**Parallel extinction.**

**Colorless.**

**Index of refraction** is **greater** than  
that of Canada balsam.

**Maximum birefringence** is **greater**  
than that of quartz.

**Biaxial.**

BIAXIAL.

*Cut on line.*



**Cordierite.**— $\text{Mg}_2\text{Al}_2\text{Si}_2\text{O}_{10}$ ,  $H = 7.0-7.5$ ,  $G = 2.59-2.66$ .  
 Orthorhombic. (—).  
 Cleavage: (010), poor.  
 Habit: Grains, short prisms. Trillings and polysynthetic twins occur.  
 Elongation: (110):(1 $\bar{1}$ 0), short laths. (—).  
 Orientation:  $b = c$ ,  $c = a$ .  
 Colorless, bluish, yellowish.  
 Pleochroism: Wanting or weak with  $b > c > a$ .  
 $\alpha = 1.535$ ,  $\beta = 1.540$ ,  $\gamma = 1.544$ .  
 $\gamma - \alpha = 0.009$ ,  $\gamma - \beta = 0.004$ ,  $\beta - \alpha = 0.005$ .  
 Dispersion: Weak with  $\rho < \nu$ .  
 $2E = 63^\circ-150^\circ$ .

When treated with HF gives characteristic prismatic crystals of magnesium fluosilicate.

**Quartz** has higher interference colors, is uniaxial, and (+).  
 Chemically different, reactions as above.

**Dumortierite.**— $3(\text{Al}_8\text{Si}_3\text{O}_{18}) \cdot \text{AlB}_3\text{O}_6 \cdot 2\text{H}_2\text{O}$ ,  $H = 7.0$ ,  $G = 3.22-3.36$ .  
 Orthorhombic. (—).  
 Cleavage: (100), good.  
 Habit: Prisms, needles.  
 Elongation: (110):(1 $\bar{1}$ 0), long lath-shaped. (—).  
 Orientation:  $a = c$ ,  $c = a$ .  
 Blue, brownish, greenish, colorless.  
 Pleochroism:  $a = \text{blue}$ ;  $b = \text{yellowish}$ , reddish violet, greenish;  
 $c = \text{colorless}$ . Strong.  
 $\alpha = 1.678$ ,  $\beta = 1.686$ ,  $\gamma = 1.689$ .  
 $\gamma - \alpha = 0.011$ ,  $\gamma - \beta = 0.003$ ,  $\beta - \alpha = 0.008$ .  
 Dispersion:  $\rho > \nu$ .  
 $2V = 30^\circ$ .

Insoluble in acids, even HF.

**Blue amphibole** is monoclinic.

**Serendibite** is triclinic, extinction  $40^\circ$  ca

**Sapphirine** is monoclinic with  $c:c = 8^\circ-9^\circ$

**Grandierite** has different habit,  $a = a$ ,  $b = c$ , and strong blue-green to colorless pleochroism.

**Andalusite.**— $\text{Al}_2\text{SiO}_5$ ,  $H = 7.5$ ,  $G = 3.10-3.20$ .  
 Orthorhombic. (—).  
 Cleavage: (110), good. (110):(1 $\bar{1}$ 0) =  $89^\circ$ .  
 Habit: Prisms, grains.  
 Elongation: (110):(1 $\bar{1}$ 0), short laths. (—).  
 Orientation:  $a = c$ ,  $c = a$ .  
 Colorless, reddish.  
 Pleochroism:  $a = \text{rose}$ ,  $b = c = \text{colorless to light green}$ .





$\alpha = 1.632$ ,  $\beta = 1.638$ ,  $\gamma = 1.643$ .

$\gamma - \alpha = 0.011$ ,  $\gamma - \beta = 0.005$ ,  $\beta - \alpha = 0.006$ .

$2V = 84^\circ - 85^\circ$ .

Not attacked by HF or other acids.

**Sillimanite** is (+), has basal cleavage, and has higher double refraction.

**Topaz** has perfect basal cleavage, is (+).

**Scapolites** have higher double refraction in prisms, and are uniaxial.

**Zoisite** has (010) and (100) cleavage, and is (+);  $2V = 0^\circ - 60^\circ$ .

**Thulite** is (+);  $2V = 0^\circ - 40^\circ$ .

**Orthoclase** has lower indices of refraction.

**Prismatine** has  $2E = 65.5^\circ$ .

**Cornerupine** has  $2E = 14^\circ - 32^\circ$ .

**Antigorite.**— $H_4(Mg, Fe)_3Si_2O_9$ ,  $H = 2.5$ ,

$G = 2.622$ .

Orthorhombic. (—).

Habit: Lamellæ, leaves, scales.

Elongation: At right angles to (100), lath-shaped. (+).

Orientation:  $a = a$ ,  $b = c$ .

Greenish, colorless, yellowish.

Non-pleochroic.

$\alpha = 1.560$ ,  $\beta = 1.570$ ,  $\gamma = 1.571$ .

$\gamma - \alpha = 0.011$ ,  $\gamma - \beta = 0.001$ ,  $\beta - \alpha = 0.010$ .

Dispersion:  $\rho > \nu$ .

$2E = 16^\circ - 98^\circ$ .

In boiling HCl silica separates.

**Pennine** is pleochroic, the double refraction is lower and the indices are higher.

**Ordinary serpentine** is (+).

**Bastite.**—Serpentine pseudomorph after an orthorhombic pyroxene,

$H = 3.5 - 4.0$ ,  $G = 2.6 - 2.8$ .

Orthorhombic. (—).

Cleavage: (100), good.

Habit: Leaves.

Elongation: (110), ( $1\bar{1}0$ ), lath-shaped. (+).

Orientation:  $a = a$ ,  $c = c$ .

Greenish, yellowish, colorless.

Pleochroism: Weak or wanting.

Index: 1.5–1.6.

Birefringence: Weak.

Dispersion:  $\rho > \nu$ .

$2E = 20^\circ - 90^\circ$ .

Gelatinizes more or less easily with acids.

**Other pyroxenes** differ in orientation. See Part II.

Cut on line.



**Hypersthene.**—(Fe, Mg)SiO<sub>3</sub>, H = 5.0-6.0, G = 3.40-3.50.

Orthorhombic. (-).

Cleavage: (010), distinct; (100), good; (110), good. (110):(110) = 91° 40'.

Habit: Prismatic, often massive.

Elongation: (110):(110), lath-shaped. (+).

Orientation:  $b = a$ ,  $c = c$ .

Colorless, yellowish, reddish.

Pleochroism:  $c$  = greenish,  $a$  = reddish yellow,  $b$  = reddish brown. Strong.

$\alpha = 1.692$ ,  $\beta = 1.702$ ,  $\gamma = 1.705$ .

$\gamma - \alpha = 0.013$ ,  $\gamma - \beta = 0.003$ ,  $\beta - \alpha = 0.010$ .

Dispersion:  $\rho > \nu$ .

$2E = 85^\circ$  ca.

Partially decomposed by HCl.

**Bronzite** is (+) and has weaker pleochroism.

**Monoclinic pyroxenes** have inclined extinction and higher double refraction. Basal sections showing cleavage give the emergence of an axis, while orthorhombic pyroxenes show the emergence of a positive bisectrix. See Part II also.

**Ægirite** has different pleochroism, greens to yellowish greens, higher double refraction, and has (-) elongation.

**Cornerupine.**—MgAl<sub>2</sub>SiO<sub>6</sub> ca., H = 6.5, G = 3.273.

Orthorhombic. (-).

Cleavage: (110) distinct. (110):(110) = 81°.

Habit: Prismatic.

Elongation: (110):(110), lath-shaped.

Orientation:  $b = c$ ,  $c = a$ .

Colorless in transmitted light.

Non-pleochroic.

$\alpha = 1.669$ ,  $\beta = 1.681$ ,  $\gamma = 1.682$ .

$\gamma - \alpha = 0.013$ ,  $\gamma - \beta = 0.001$ ,  $\beta - \alpha = 0.012$ .

Dispersion: Not apparent.

$2E = 32^\circ 30'$ . (Also  $26^\circ$ ,  $19^\circ$ ,  $14^\circ$ .)

Insoluble in acids.

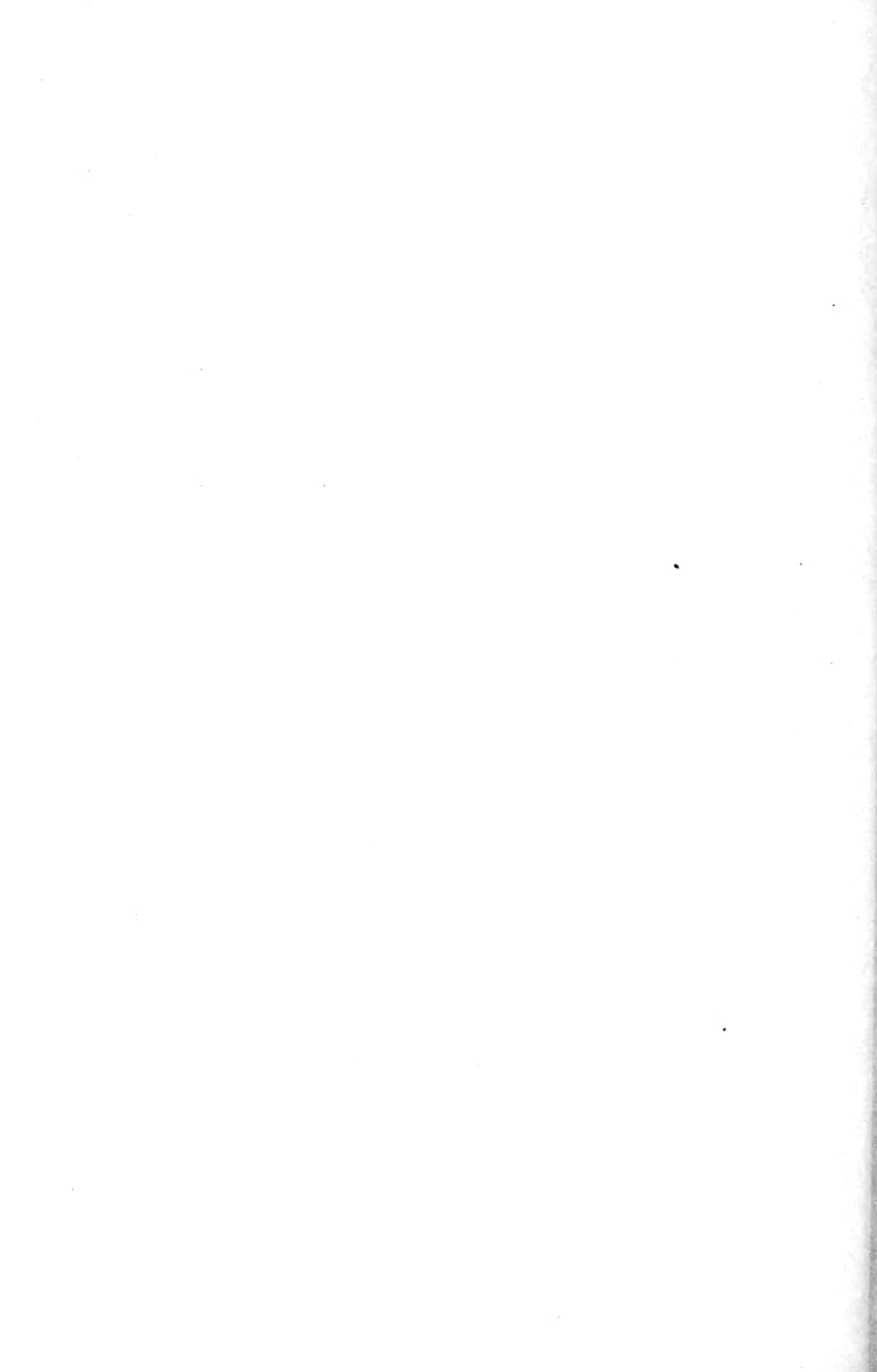
**Prismatine** is yellowish, slightly pleochroic,  $G = 3.341$ , and  $2E = 65.5^\circ$ ; otherwise they are alike.

**Sillimanite** has good (100) cleavage and higher double refraction.

**Topaz** has good basal cleavage.

**Andalusite** generally has larger value for  $2E$ .

Cut on line.



Monticellite.— $\text{MgCaSiO}_4$ ,  $H = 5.0\text{--}6.0$   $G = 3.12\text{--}3.275$ .

Orthorhombic. (—).

Habit: Isometric, grains.

Orientation:  $a = c$ ,  $b = a$ .

Colorless.

$\alpha = 1.651$ ,  $\beta = 1.662$ ,  $\gamma = 1.668$ .

$\gamma - \alpha = 0.017$ ,  $\gamma - \beta = 0.006$ ,  $\beta - \alpha = 0.011$ .

Dispersion: Distinct,  $\rho > \nu$ .

$2V = 37^\circ 31'$ .

Soluble in HCl.

A member of the olivine group.

Olivine and forsterite have much larger axial angles, are (+), and have higher birefringence.

Fayalite has  $2V = 50^\circ$  ca., is usually colored, has higher birefringence and higher indices of refraction.

Gedrite.— $(\text{Mg, Fe})\text{SiO}_3$  and  $(\text{Mg, Fe})\text{Al}_2\text{SiO}_6$ ,  $H = 5.5\text{--}6.0$ ,  $G = 3.1\text{--}3.2$ .

Orthorhombic. (—).

Cleavage: (110), good; (100), distinct; (010), poor. (110):(110) =  $55^\circ 12'$

Habit: Rods, leaves, grains.

Elongation: (110):(110), lath-shaped. ( $\perp$ ).

Orientation:  $a = a$ ,  $c = c$ .

Colorless, yellowish, brownish, greenish.

Pleochroism:  $\epsilon$  = yellowish, brownish;  $\eta$  = clove-brown, reddish;

$\alpha$  = yellowish, greenish, colorless.

$\alpha = 1.623$ ,  $\beta = 1.636$ ,  $\gamma = 1.644$ .

$\gamma - \alpha = 0.021$ ,  $\gamma - \beta = 0.008$ ,  $\beta - \alpha = 0.013$ .

Dispersion:  $\rho > \nu$ .

$2V = 79^\circ\text{--}57^\circ$ .

Not affected by acids.

A member of the orthorhombic amphibole group.

Other amphiboles. See Part II.

Pistacite.—(Epidote),  $\text{Al}(\text{SiO}_3)_2(\text{Al, Fe})_2\text{Ca} \cdot \text{CaOH}$ ,  $H = 6.5$ ,  $G = 3.3\text{--}3.5$ .

Monoclinic. (—).

Cleavage: (001), good; (100), distinct. (001):(100) =  $64^\circ 37'$ .

Habit: Prisms, and rods elongated along  $b$ , grains; twinning (100).

Elongation: (001):(100), lath-shaped. ( $\pm$ ).

Orientation:  $b = b$ ,  $c: a = +3^\circ$ .

Green, yellow, brownish, colorless.

Pleochroism:  $\alpha$  = colorless to yellowish or greenish;  $\eta$  = yellowish to yellowish gray, lavender;  $\epsilon$  = green, light yellowish brown.

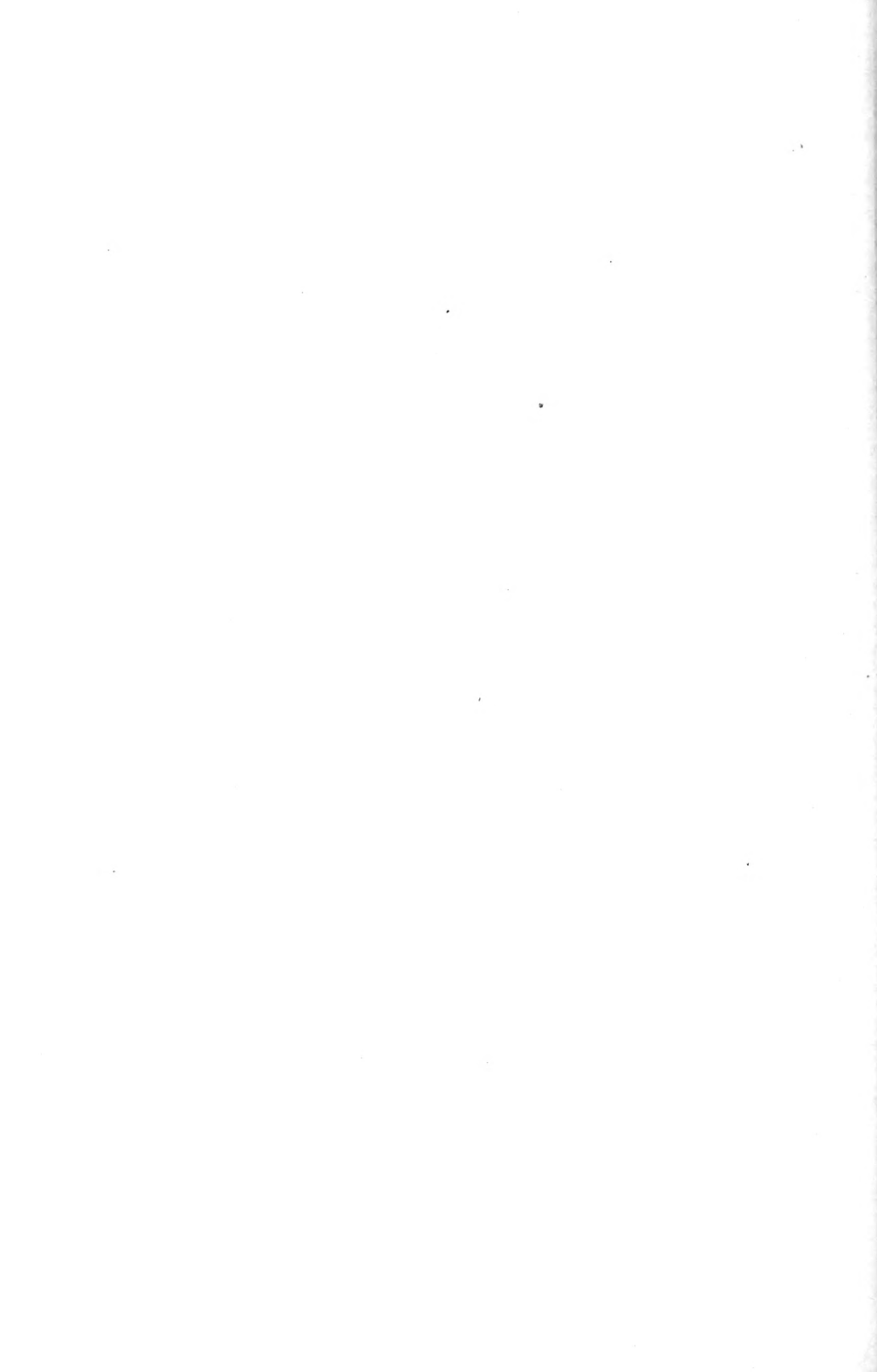
$\alpha = 1.714$ ,  $\beta = 1.741$ ,  $\gamma = 1.746$ .

$\gamma - \alpha = 0.032$ ,  $\gamma - \beta = 0.005$ ,  $\beta - \alpha = 0.027$ .

Dispersion:  $\rho > \nu$ .

$2V = 74^\circ\text{--}90^\circ$ .

*Cut on line.*



Not affected by HCl.

Pistacite is the Fe-rich epidote; clinozoisite, the Fe-poor or Fe-free.

**Pyroxene** has (110) cleavage; in sections parallel to the long direction the plane of the optic axes is parallel to the cleavage; in epidote at right angles to it.

**Clinozoisite** has lower double refraction, is (+), and has strong  $\rho < \nu$  dispersion.

**Piedmontite.**— $\text{Al}(\text{SiO}_4)_3(\text{Al}, \text{Mn}, \text{Fe})_2\text{Ca} \cdot \text{CaOH}$ ,  $H=6.5$ ,  $G=3.40$ .

Monoclinic. (−). Mn-rich piedmontite is (+).

Cleavage: (001), good; (100), distinct.  $(001):(\bar{1}01)=63^\circ 30.5'$ .

Habit: Prisms, rods elongated along  $b$ , grains.

Elongation: (001):(100), lath-shaped. ( $\pm$ ).

Orientation:  $b=\mathbf{b}$ ,  $c:\mathbf{a}=+5^\circ$  to  $+6^\circ$ .

Red, yellow, colorless.

Pleochroism: Strong and characteristic;  $\mathbf{a}$ =orange;  $\mathbf{b}$ =violet, amethyst;  $\mathbf{c}$ =red.

Indices similar to pistacite.

Birefringence similar to pistacite.

$2V=90^\circ$ ; it becomes greater than  $90^\circ$  in the Mn-rich piedmontites, and the mineral becomes optically (+).

A manganese epidote.

Insoluble in HCl.

**Pistacite**, **clinozoisite**, and **orthite** have different pleochroism.

**Other minerals** are separated by the epidote-like character of piedmontite and by the pleochroism.

**Paragonite.**— $\text{Al}(\text{SiO}_4)_3\text{Al}_2\text{NaH}_7$ ,  $H=2.0-2.5$ ,  $G=2.8-2.9$ .

Monoclinic. (−).

Cleavage: (001), good.

Habit: Leaves, leafy aggregates.

Elongation: Perpendicular to (001), lath-shaped. (+).

Orientation:  $b=\mathbf{c}$ ,  $c:\mathbf{a}=+0^\circ$  to  $+2^\circ$ .

Colorless, greenish, yellowish.

Pleochroism: Weak or none.

Indices: Very similar to muscovite (see below).

Birefringence: Like muscovite (see below).

Dispersion: Weak,  $\rho > \nu$ .

$2E=70^\circ$  ca.

Insoluble in acids.

One of the mica group.

**Muscovite** and **lepidolite** are different chemically.

**Talc** has  $2E=6^\circ-20^\circ$ .

Cut on line.





**Muscovite.**— $\text{Al}(\text{SiO}_4)_3\text{KH}_2\text{Al}_2$ ,  $H=2.0-2.5$ ,  $G=2.8-2.9$ .

Monoclinic. (—).

Cleavage: (001), good.

Habit: Leaves, leafy aggregates.

Elongation: Perpendicular to (001), lath-shaped. (+).

Orientation:  $b=a$ ,  $c:a=+0^\circ$  to  $+2^\circ$ .

Colorless, greenish, yellowish.

Pleochroism: Weak or wanting.

$\alpha=1.563$ ,  $\beta=1.598$ ,  $\gamma=1.601$ .

$\gamma-\alpha=0.038$ ,  $\gamma-\beta=0.003$ ,  $\beta-\alpha=0.035$ .

Dispersion: Weak,  $\rho>\nu$ .

$2E=60^\circ-70^\circ$ .

Insoluble in  $\text{HCl}$  and  $\text{H}_2\text{SO}_4$ . One of the Mica group.

Micas can only be confused with other minerals that have complete basal cleavage. The very low birefringence in basal sections and high birefringence in sections showing cleavage is very characteristic of the micas.

Chlorites have weak double refraction.

Talc has  $2E=6^\circ-20^\circ$ .

Biotite has  $2E$  generally much smaller, also  $b=b$ .

Lepidolite and paragonite may be separated by flame test for Li and treatment with  $\text{HF}$ , by which muscovite will give many crystals of  $\text{K}_2\text{SiF}_6$  and few  $\text{NaSiF}_6$ . See also Part II.

**Lepidolite.**— $\text{Al}(\text{SiO}_4)_2\text{Al}_2\text{KLiH} + \text{Al}(\text{Si}_3\text{O}_{10})_3\text{K}_3\text{Li}_3(\text{AlF}_2)_3$ ,  $H=2.5-4.0$ ,

$G=2.8-2.9$ .

Monoclinic. (—).

Cleavage: (001), good.

Habit: Leaves, leafy aggregates.

Elongation: At right angles to (001), lath-shaped. (+).

Orientation:  $b=a$ ,  $c:a=+0^\circ$  to  $+2^\circ$ ; or rarely  $b=b$ ,  $c:a=+0^\circ$  to  $+2^\circ$ .

Colorless, reddish.

Pleochroism: Weak or none

$\beta=1.598$ ,  $\gamma=1.605$ .

$\gamma-\beta=0.007$ .

Dispersion: Weak,  $\rho\gtrsim\nu$ .

$2E=32^\circ-84^\circ$ .

Insoluble in acids.

Muscovite and paragonite do not give Li flame.

See also under muscovite.

**Datolite.**— $\text{HCaBSiO}_3$ ,  $H=5.0-5.5$ ,  $G=2.9-3.0$ .

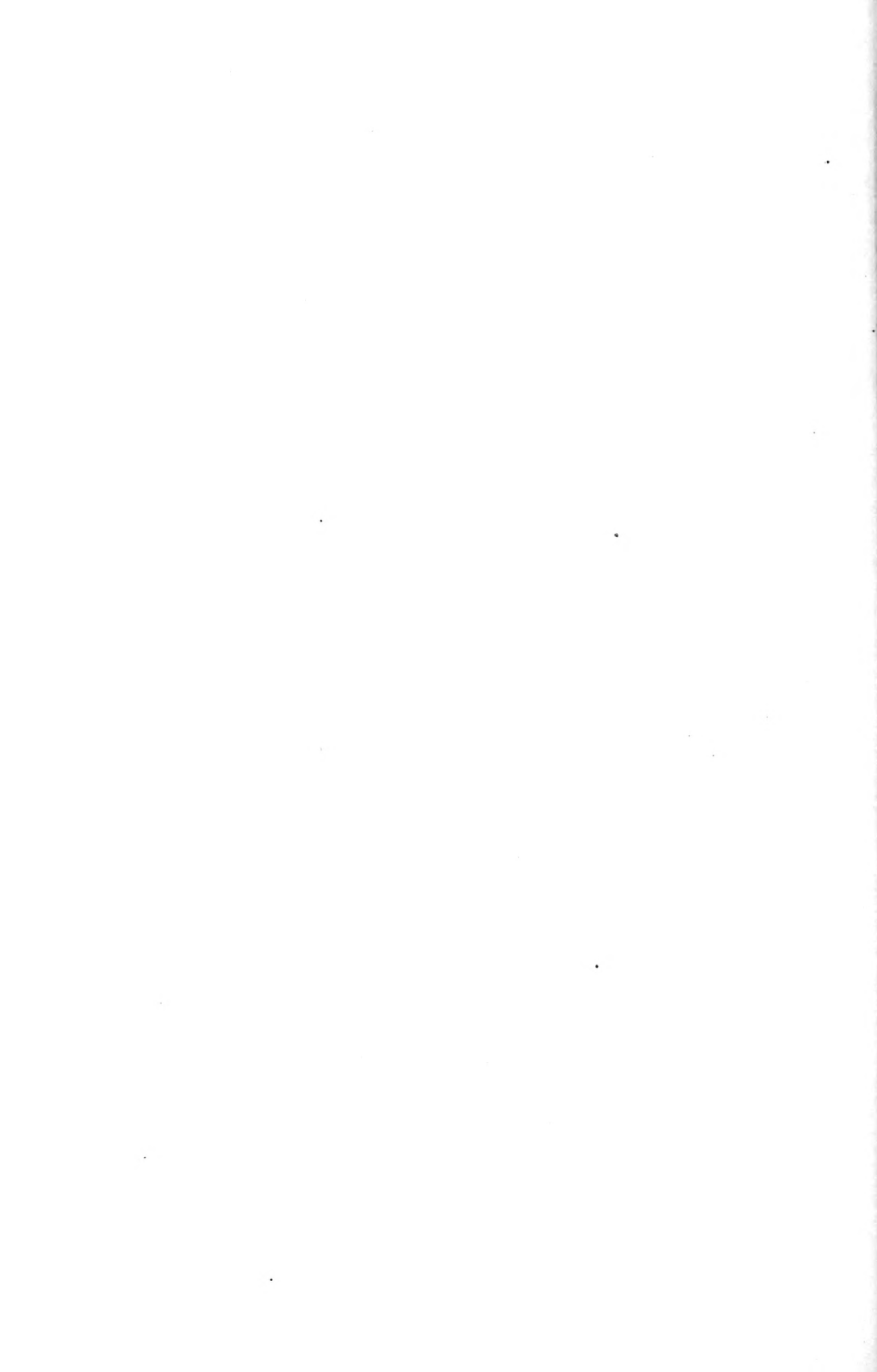
Monoclinic. (—).

No distinct cleavage.

Habit: Grains, rods.

Orientation:  $b=b$ ,  $c:a=+1^\circ$  to  $+12^\circ$ .

*Cut on line.*



Colorless.

$\alpha = 1.625$ ,  $\beta = 1.653$ ,  $\gamma = 1.669$ .

$\gamma - \alpha = 0.044$ ,  $\gamma - \beta = 0.016$ ,  $\beta - \alpha = 0.028$ .

Dispersion: Weak,  $\rho > \nu$ .

$2V = 74^\circ$ .

Gelatinizes with HCl. Gives reaction for boron.

**Pistacite** has cleavage, no B reaction, and has lower birefringence.

**Phlogopite**.—A magnesium mica, near biotite, but containing little Fe,  
H=2.5-3.0, G=2.78-2.85.

Monoclinic. (-).

Cleavage: (001), good.

Habit: Leaves, leafy aggregates.

Elongation: At right angles to (001), lath-shaped. (+).

Orientation:  $b = \mathbf{b}$ ,  $c : \mathbf{a} = 0^\circ$  to  $+7^\circ$

Colorless, yellowish, brownish, greenish.

Pleochroism: Weak, with  $\mathbf{r} > \mathbf{b} > \mathbf{a}$ .

$\alpha = 1.562$ ,  $\beta = 1.606$ ,  $\gamma = 1.606$ .

$\gamma - \alpha = 0.044$ ,  $\gamma - \beta = 0.0$ ,  $\beta - \alpha = 0.044$ .

Dispersion: Weak,  $\rho < \nu$ .

$2E$  small to  $0^\circ$ .

Completely decomposed by  $\text{H}_2\text{SO}_4$ , leaving the silica in thin flakes. One of the micas.

**Other micas**: Phlogopite has small to very small  $2V$ , and has symmetrical position of the plane of the optic axes. See muscovite, also Part II.

**Fayalite**.— $\text{Fe}_2\text{SiO}_4$ , H=6.5-7.0, G=4.1.

Orthorhombic. (-).

Cleavage: (100), poor.

Habit: Isometric, short prisms, grains.

Orientation:  $a = \mathbf{r}$ ,  $b = \mathbf{a}$ .

Greenish, yellowish, red, colorless.

Pleochroism: Wanting or weak in yellow and red tones.

$\alpha = 1.824$ ,  $\beta = 1.864$ ,  $\gamma = 1.874$ .

$\gamma - \alpha = 0.050$ ,  $\gamma - \beta = 0.010$ ,  $\beta - \alpha = 0.040$ .

Dispersion: Distinct,  $\rho > \nu$ .

$2V = 50^\circ$  ea.

An iron rich olivine.

Gelatinizes quite easily with HCl.

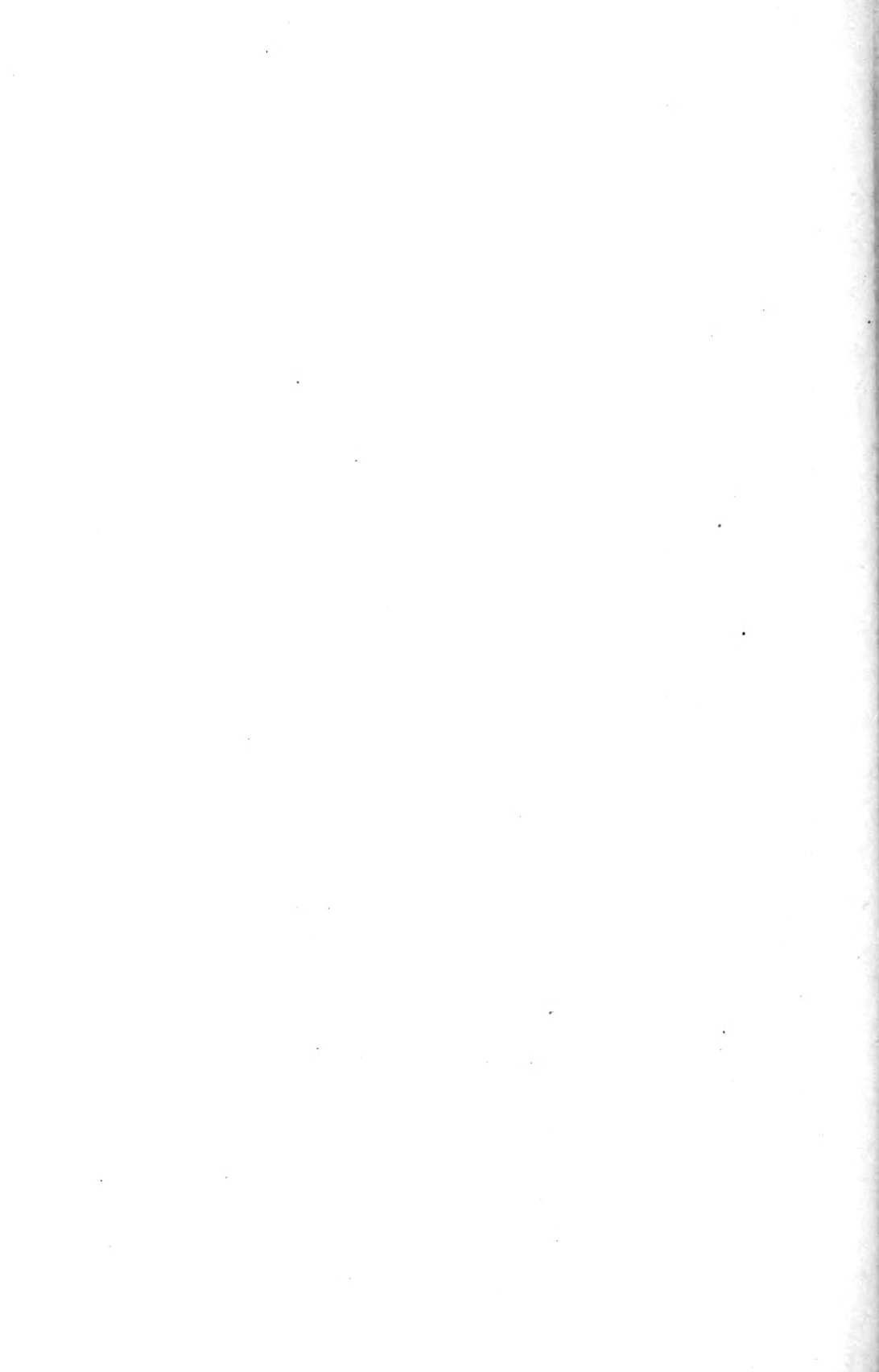
**Olivine** has  $2V = 88^\circ$ , is (+), and has lower birefringence.

**Forsterite** is (+), has  $2V = 86^\circ$ , lower indices, and different occurrence.

**Monticellite** has  $2V = 37.5^\circ$ , has lower indices and lower double refraction.

See also Part II, olivine group.

Cut on line.



**Talc.**—  $\text{H}_2\text{Mg}_3\text{Si}_4\text{O}_{12}$ ,  $\text{H} = 1.0$ ,  $\text{G} = 2.7-2.8$ .  
 Orthorhombic. (-).  
 Cleavage: (001), good.  
 Habit: Leaves, scales.  
 Elongation: At right angles to (001), lath-shaped. (+).  
 Orientation:  $b = c$ ,  $c = a$ .  
 Colorless, greenish, bluish.  
 Non-pleochroic.  
 $\alpha = 1.539$ ,  $\beta = 1.589$ ,  $\gamma = 1.589$ .  
 $\gamma - \alpha = 0.050$ ,  $\gamma - \beta = 0.000$ ,  $\beta - \alpha = 0.050$ .  
 Dispersion: Distinct,  $\rho > \nu$ .  
 $2E = 6^\circ-20^\circ$ .

Hardly affected by acids.

**Brucite** is (+), uniaxial, and has lower double refraction.

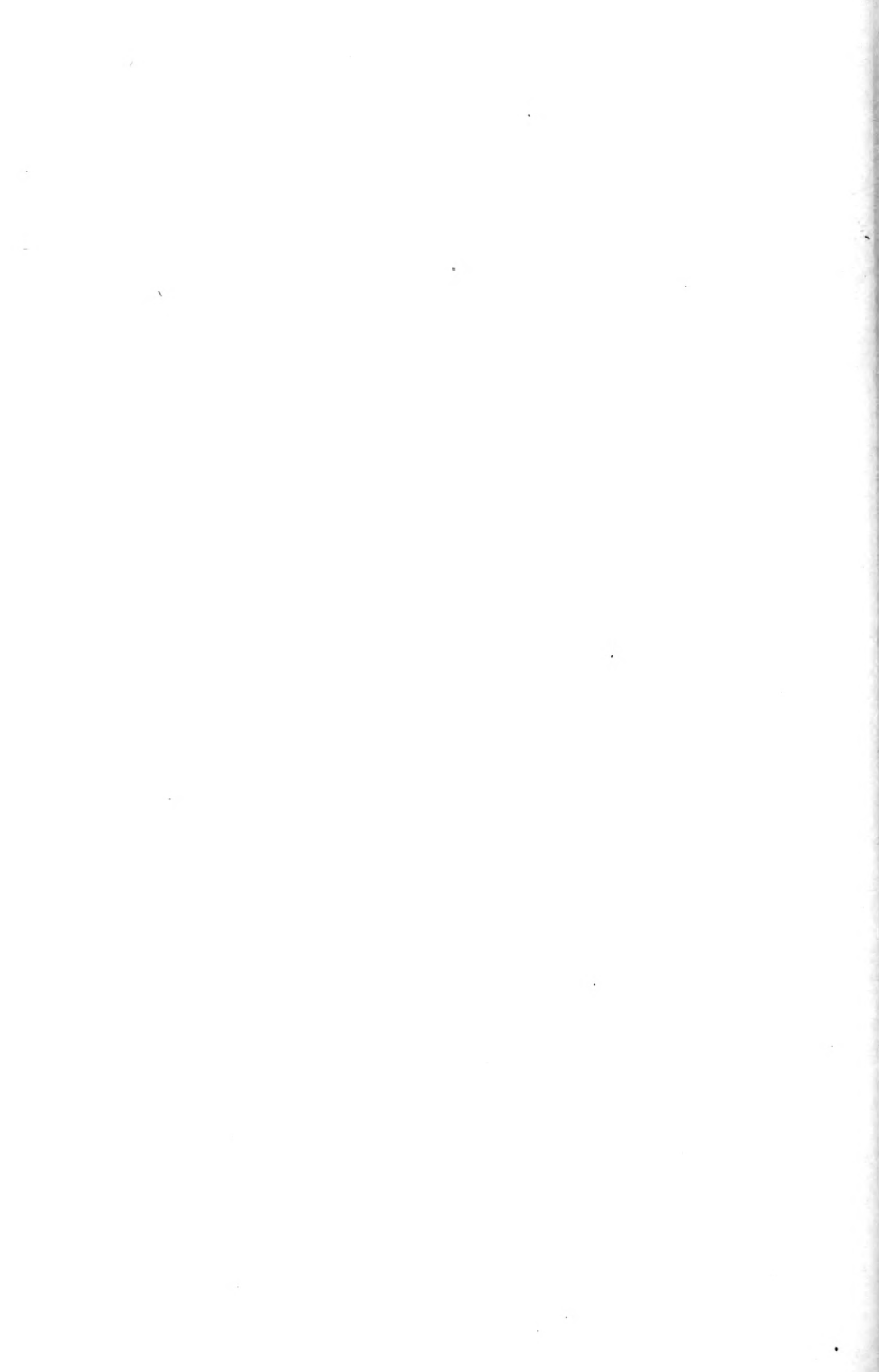
**Muscovite** cannot be separated optically when it has a small value for  $2E$ ; it must be separated by testing for the alkalies or with cobalt solution.

**Aragonite.**— $\text{CaCO}_3$ ,  $\text{H} = 3.5-4.0$ ,  $\text{G} = 2.93-2.95$ .  
 Orthorhombic. (-).  
 Cleavage: Not recognizable under the microscope.  
 Habit: Rods, grains.  
 Elongation: (110):(1 $\bar{1}$ 0), lath-shaped. (-).  
 Orientation:  $b = c$ ,  $c = a$ .  
 Colorless.  
 Non-pleochroic.  
 $\alpha = 1.530$ ,  $\beta = 1.682$ ,  $\gamma = 1.686$ .  
 $\gamma - \alpha = 0.156$ ,  $\gamma - \beta = 0.004$ ,  $\beta - \alpha = 0.152$ .  
 Dispersion: Weak,  $\rho < \nu$ .  
 $2V = 18^\circ$ .

Soluble in HCl with effervescence.

**Calcite** is separated chemically (see Part II), is uniaxial, and has good cleavage.

*Cut on line.*



**Topaz.**—  $\text{Al}_2\text{SiO}_4(\text{F},\text{OH})_2$ ,  $\text{H}=8.0$ ,  $\text{G}=3.533\text{--}3.574$ .  
 Orthorhombic. (+).  
 Cleavage: (001), good.  
 Habit: Short prisms, grains, rods.  
 Elongation: (001). (-).  
 Orientation:  $a = a$ ,  $c = c$ .  
 Colorless.  
 Pleochroism: None in thin sections.  
 $\alpha=1.619$ ,  $\beta=1.622$ ,  $\gamma=1.628$ .  
 $\gamma-\alpha=0.009$ ,  $\gamma-\beta=0.006$ ,  $\beta-\alpha=0.003$ .  
 Dispersion:  $\rho > \nu$ .  
 $2E=71^\circ\text{--}129^\circ$ .

Occurs in schists, gneisses, and in cavities of volcanic rocks.

Insoluble in acids.

**Quartz** has lower indices and no cleavage, basal sections give uniaxial interference figures.

**Andalusite** is (-), has good (110) cleavage, and different orientation.

**Sillimanite** and **prismatine** have different orientation.

**Enstatite.**—  $(\text{Mg},\text{Fe})_2\text{Si}_2\text{O}_6$ ,  $\text{H}=5.0\text{--}6.0$ ,  $\text{G}=3.1$ .  
 Orthorhombic. (+).  
 Cleavage: (110), good; (010), distinct; (100), good. (110):(110) =  $91^\circ 40'$ .  
 Habit: Prismatic, cloudy masses.  
 Elongation: (110):(110), lath-shaped. (+).  
 Orientation:  $b = a$ ,  $c = c$ .  
 Colorless.  
 Pleochroism: Wanting.  
 $\alpha=1.656$ ,  $\beta=1.659$ ,  $\gamma=1.665$ .  
 $\gamma-\alpha=0.009$ ,  $\gamma-\beta=0.006$ ,  $\beta-\alpha=0.003$ .  
 Dispersion:  $\rho < \nu$ .  
 $2E=135^\circ$  ca.

Insoluble in acids.

**Monoclinic pyroxenes** have higher double refraction and inclined extinction. In basal sections the monoclinic pyroxenes show the emergence of an axis, while the orthorhombic pyroxenes show the emergence of a positive bisectrix.

**Ægirite** is pleochroic, has higher double refraction, and (-) elongation.

**Bastite** cleavage flakes along the best pinacoidal cleavage show the emergence of a negative bisectrix with small axial angle; enstatite shows the emergence of the optic normal.

**Diallage**, in similar flakes, shows the emergence of an optic axis.





**Bronzite.**— $(\text{Mg,Fe})_2\text{Si}_2\text{O}_6$ ,  $H = 5.0\text{--}6.0$ ,  $G = 3.29$ .  
 Orthorhombic. (+).  
 Cleavage: (010), distinct; (100), good; (110), good.  $(110):(1\bar{1}0) = 91^\circ 40'$ .  
 Habit: Prismatic, cloudy masses. Geniculated and star-shaped twins occur rarely.  
 Elongation:  $(110):(1\bar{1}0)$ , lath-shaped. (+).  
 Orientation:  $b = a$ ,  $c = c$ .  
 Colorless, yellowish, reddish.  
 Pleochroism: Weak,  $c = \text{greenish}$ ,  $a = \text{reddish yellow}$ ,  $b = \text{reddish brown}$ .  
 $\alpha = 1.665$ ,  $\beta = 1.669$ ,  $\gamma = 1.674$ .  
 $\gamma - \alpha = 0.009$ ,  $\gamma - \beta = 0.005$ ,  $\beta - \alpha = 0.004$ .  
 Dispersion:  $\rho < \nu$ .  
 $2E = 106^\circ$  ea.

An orthorhombic pyroxene.

**Hypersthene** has same pleochroism, strong, and is (-).

**Monoclinic pyroxenes.** See enstatite above; also Part II.

**Zoisite.**— $\text{HCa}_2\text{Al}_2\text{Si}_2\text{O}_8$ ,  $H = 6.0\text{--}6.5$ ,  $G = 3.25\text{--}3.37$ .  
 Orthorhombic. (+).  
 Cleavage: (010), good; (100), distinct.  
 Habit: Rods, leaves.  
 Elongation:  $(110):(1\bar{1}0)$ , short laths. ( $\pm$ ).  
 Orientation:  $a = c$ ,  $c = a$ ; or  $a = c$ ,  $b = a$ .  
 Colorless or pale bluish green.  
 Pleochroism: None in thin sections.  
 $\alpha = 1.698$ ,  $\beta = 1.699$ ,  $\gamma = 1.707$ .  
 $\gamma - \alpha = 0.009$ ,  $\gamma - \beta = 0.008$ ,  $\beta - \alpha = 0.001$ .  
 Dispersion: Strong,  $\rho < \nu$ ,  $\rho > \nu$ .  
 $2V = 0^\circ\text{--}60^\circ$ .

Insoluble in acids.

Abnormal interference colors.

**Pistacite**, with weak double refraction, is similar when the axial plane is at right angles to the cleavage.

**Vesuvianite** has poor cleavage.

**Melilite** gelatinizes with acids.

**Mosandrite.** }  $\text{Ti, Zr, Th, Ce, Y, Al, Fe, Mn, Ca, Mg, Na, K, F}$  silicate,  
**Johnstrupite.** }  $H = 4.0$  and more,  $G = 3.10\text{--}3.29$  (Johnst.),  $2.93\text{--}3.07$  (Mosan).

Monoclinic. (+).

Cleavage: (100), good.

Habit: Tablets (100), elongated on  $c$ . Twinning (100) frequent.

Elongation:  $(100):(010)$ , lath-shaped. (-).

Orientation.  $b = b$ ,  $c: a = 3^\circ$

Grayish yellow to colorless.

Cut on line.



Pleochroism: Not seen in thin sections.

$\alpha = 1.646$ ,  $\beta = 1.649$ ,  $\gamma = 1.658$ .

$\gamma - \alpha = 0.012$ ,  $\gamma - \beta = 0.009$ ,  $\beta - \alpha = 0.003$ .

Dispersion: Strong,  $\rho > \nu$ .

$2V = 70^\circ$ .  $2E_{na} = 128^\circ 37'$ .

Soluble in HCl with separation of  $\text{SiO}_2$ ; the dark-red solution on heating gives off Cl and becomes yellowish.

**Rinkite** has strong  $\rho < \nu$  dispersion, and the position of the plane of the optic axes is not symmetrical.

**Lawsonite.**— $\text{H}_2\text{CaAl}_2\text{Si}_2\text{O}_{10}$ ,  $H = 8.0$ ,  $G = 3.084\text{--}3.091$ .

Orthorhombic. (+).

Cleavage: (010), (001), good; (110), distinct.  $(110):(1\bar{1}0) = 67^\circ 16'$ .

Habit: Tablets, short plates. Twins (110).

Elongation:  $(110):(1\bar{1}0)$ , short broad laths. (+).

Orientation:  $a = a$ ,  $c = c$ .

Colorless, light blue.

Pleochroism: Very weak, almost wanting.

$\alpha = 1.665$ ,  $\beta = 1.669$ ,  $\gamma = 1.684$ .

$\gamma - \alpha = 0.019$ ,  $\gamma - \beta = 0.015$ ,  $\beta - \alpha = 0.004$ .

$2V = 84^\circ$ .

Insoluble in HCl.

**Zoisite** and **andalusite** have lower double refraction.

**Scapolites** are uniaxial.

**Cordierite** and other colorless silicates have lower indices of refraction.

**Sillimanite.**— $\text{Al}_2\text{SiO}_5$ ,  $H = 6.0\text{--}7.0$ ,  $G = 3.23\text{--}3.248$ .

Orthorhombic. (+).

Cleavage: (100), good.

Habit: Prisms, threads.

Elongation:  $(110):(1\bar{1}0)$ , long laths. (+).

Orientation:  $b = a$ ,  $c = c$ .

Colorless, yellowish, cloudy.

Pleochroism: Not seen in thin sections.

$\alpha = 1.660$ ,  $\beta = 1.661$ ,  $\gamma = 1.682$

$\gamma - \alpha = 0.022$ ,  $\gamma - \beta = 0.021$ ,  $\beta - \alpha = 0.001$ .

Dispersion: Strong,  $\rho > \nu$ .

$2V = 31^\circ\text{--}42^\circ$ .

Insoluble in acids.

**Andalusite** is (−) and has (−) elongation, double refraction is lower, and relation of axial plane to cleavage is different.

**Scapolites** are (−), have (−) elongation, and are uniaxial.

**Zoisite** has weaker double refraction and different orientation.

Cut on line.



**Anthophyllite.**— $(\text{Mg,Fe})\text{SiO}_3$ ,  $H = 5.5-6.0$ ,  $G = 3.1-3.2$ .  
 Orthorhombic.  $(\pm)$ .  
 Cleavage:  $(110)$ , good;  $(100)$ , distinct;  $(010)$ , poor.  $(110):(1\bar{1}0) = 54^\circ 23'$ .  
 Habit: Rods, leaves, grains.  
 Elongation:  $(110):(1\bar{1}0)$ , lath-shaped.  $(+)$ .  
 Orientation:  $a = a$ ,  $c = c$ .  
 Colorless, yellowish, brownish, greenish.  
 Pleochroism:  $c$  = yellowish, brownish;  $b$  = clove-brown, reddish;  
 $a$  = yellowish, greenish, colorless.  
 $\alpha = 1.633$ ,  $\beta = 1.642$ ,  $\gamma = 1.657$ .  
 $\gamma - \alpha = 0.024$ ,  $\gamma - \beta = 0.015$ ,  $\beta - \alpha = 0.009$ .  
 Dispersion:  $\rho < \nu$ ,  $\rho > \nu$ .  
 $2V \geq 90^\circ$ .

Not noticeably affected by acids.

A member of the amphibole group.

**Amphiboles and pyroxenes**, see Part II.

**Manganese rich Piedmontite.** See piedmontite above.

**Prehnite.**— $\text{H}_2\text{Ca}_2\text{Al}_2\text{Si}_2\text{O}_{12}$ ,  $H = 6.0-6.5$ ,  $G = 2.80-2.95$ .  
 Orthorhombic.  $(+)$ .  
 Cleavage:  $(001)$ , good.  
 Habit: Tablets, leafy aggregates.  
 Elongation:  $(001)$ , lath-shaped.  $(-)$ .  
 Orientation:  $a = a$ ,  $c = c$ .  
 Colorless.  
 Non-pleochroic.  
 $\alpha = 1.616$ ,  $\beta = 1.626$ ,  $\gamma = 1.649$ .  
 $\gamma - \alpha = 0.033$ ,  $\gamma - \beta = 0.023$ ,  $\beta - \alpha = 0.010$ .  
 Dispersion: Weak,  $\rho \geq \nu$ .  
 $2V = 69^\circ$ .

Optical anomalies not rare.

Attacked with difficulty by acids.

**Thomsonite** has lower indices and is more easily attacked by acids.

**Andalusite**, **topaz**, **cordierite** and **zoisite** have lower double refraction.

**Datolite** gives reaction for B., and has higher double refraction.

**Forsterite.**— $\text{Mg}_2\text{SiO}_4$ ,  $H = 7$ ,  $G = 3.21-3.32$ .  
 Orthorhombic.  $(+)$ .  
 Cleavage:  $(010)$ ,  $(001)$ , distinct.  
 Habit: Isometric, short prisms, grains.  
 Orientation:  $a = c$ ,  $b = a$ .  
 Colorless.  
 Index:  $\beta = 1.659$ .  
 Birefringence: High.



Dispersion: Weak,  $\rho < \nu$ .

$2V = 86^\circ$ .

A member of the olivine group. Occurs as a contact mineral in metamorphosed limestones.

**Monticellite** is (-), has smaller  $2V$ , dispersion  $\rho > \nu$ , and different occurrence.

**Piedmontite** has characteristic pleochroism.

**Humite.**—  $\text{Mg}_3[\text{Mg}(\text{F}, \text{OH})_2](\text{SiO}_4)_3$ ,  $H = 6.5$ ,  $G = 3.1-3$ .

Orthorhombic. (+).

Cleavage: (001), distinct.

Habit: Grains. Twins. Often lamellar.

Orientation:  $a = a$ ,  $b = c$ .

Colorless, yellow, yellowish brown, reddish.

Pleochroism: Weak in yellow and colorless tones.

$\beta = 1.643$ .

$\gamma = 0.035$ .

Dispersion: Weak,  $\rho > \nu$ .

$2V = 68^\circ$ .

Gelatinizes quite easily with HCl.

Occurs as a not especially common constituent of crystalline dolomites and limestones.

**Olivine** resembles colorless humite, but has the plane of the optic axes at right angles to the cleavage, while in humite it is parallel to the cleavage.

**Olivine.**—  $(\text{Mg}, \text{Fe})\text{SiO}_4$ ,  $H = 6.5-7.0$ ,  $G = 3.27-3.45$ .

Orthorhombic. (+).

Cleavage: (010), (001), distinct; (100), poor. Generally shows heavy, irregular cracks.

Habit: Isometric, short prisms, grains. Twins (011) and (012), rare.

Orientation:  $a = c$ ,  $b = a$ .

Greenish, yellowish, reddish, colorless.

Pleochroism: Wanting or weak in yellow and red tones.

$\alpha = 1.654$ ,  $\beta = 1.670$ ,  $\gamma = 1.689$ .

$\gamma - \alpha = 0.035$ ,  $\gamma - \beta = 0.019$ ,  $\beta - \alpha = 0.016$ .

Dispersion: Distinct,  $\rho < \nu$ .

$2V = 88^\circ$  ca.

Gelatinizes slowly in HCl.

**Diopside** has two equally good cleavages to which the extinction is inclined; olivine has two very unequal cleavages to which the extinction is parallel in the principal zone. Diopside does not gelatinize with HCl.

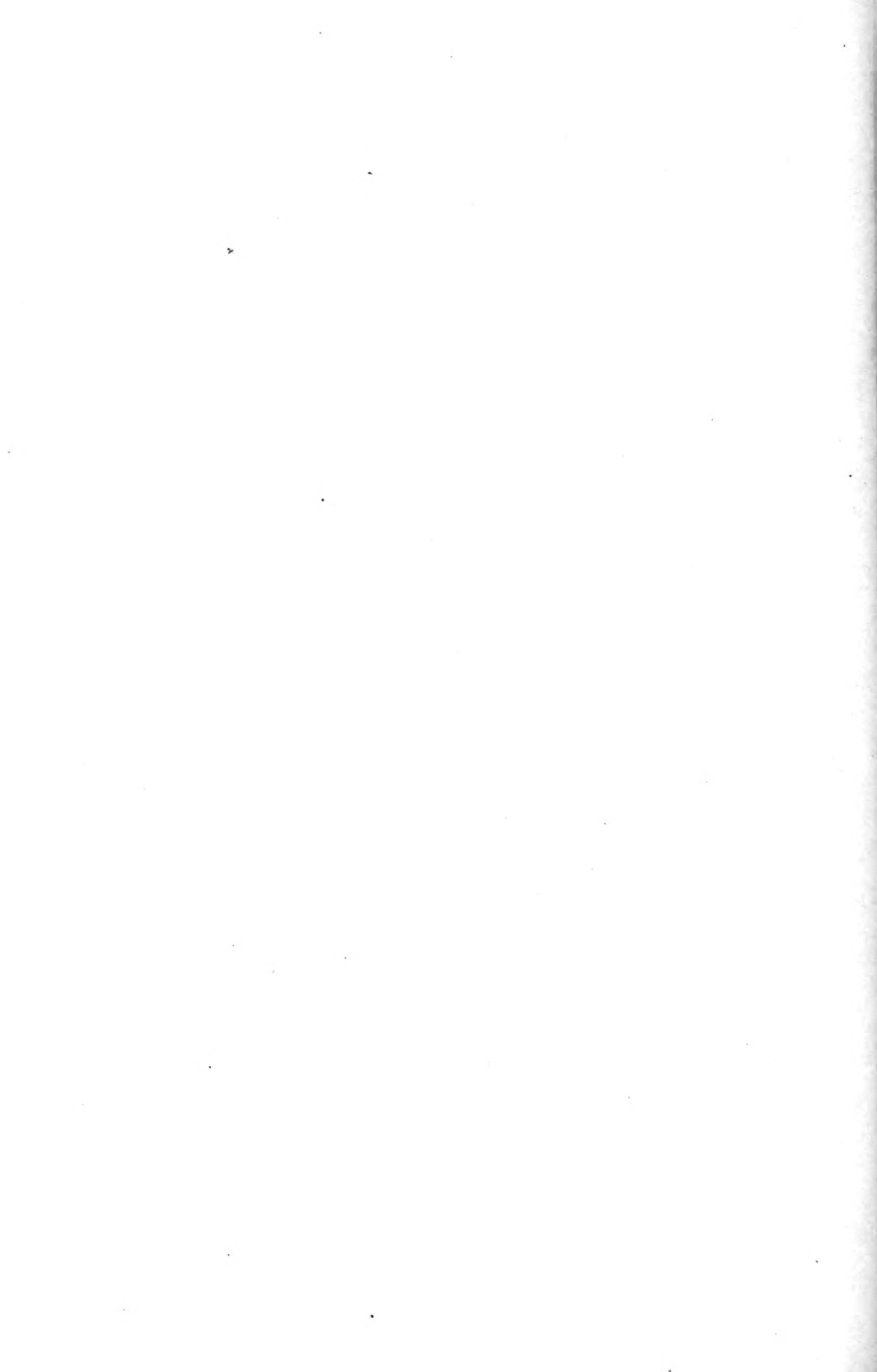
**Fayalite** has  $2V = 50^\circ$ , higher birefringence, and is (-).

**Forsterite** has lower indices, and occurs as a contact mineral in metamorphosed limestones.

**Monticellite** is (-), and has  $2V = 37.5^\circ$ .

**Augite** and **diallage**, when they have parallel extinction, differ in orientation of interference figures.

Cut on line.





**Pectolite.**— $\text{NaHCa}_2\text{Si}_3\text{O}_9$ ,  $H = 4.5-5.0$ ,  $G = 2.74-2.88$ .

Monoclinic. (+).

Cleavage: (100), good; (001), distinct.  $(100):(001) = 84.5^\circ$ .

Habit: Tablets; rods along  $b$ .

Elongation: Laths, tabular. (+).

Orientation:  $b = c$ ,  $c : a = -5^\circ$ .

Colorless.

Non-pleochroic.

Index:  $n = 1.61$  ca.

Birefringence:  $\gamma - \alpha = 0.038$ .

$2V = 60^\circ$ .

Soluble in HCl.

Wollastonite is (-), has ( $\pm$ ) elongation, lower double and higher indices of refraction, and  $c : a = +32^\circ$ .

**Anhydrite.**— $\text{CaSO}_4$ ,  $H = 3.0-3.5$ ,  $G = 2.9-3.0$ .

Orthorhombic. (+).

Cleavage: (001), (010), (100), good.

Habit: Grains, seldom threads.

Orientation:  $a = c$ ,  $c = a$

Colorless.

• Non-pleochroic.

$\alpha = 1.570$ ,  $\beta = 1.576$ ,  $\gamma = 1.614$ .

$\gamma - \alpha = 0.044$ ,  $\gamma - \beta = 0.038$ ,  $\beta - \alpha = 0.006$ .

Dispersion: Strong,  $\rho < \nu$ .

$2E = 71.5^\circ$ .

Slowly soluble in HCl.

Gypsum has lower double refraction and extinction  
 $c : a = -53^\circ$ .

**Monazite.**— $(\text{Ce}, \text{La}, \text{Di})\text{PO}_4$ ,  $H = 5.5$ ,  $G = 4.9-5.3$ .

Monoclinic. (+).

Cleavage: (100), (010) distinct.

Habit: Tablets, often elongated on  $b$ .

Elongation: (001):(100), short laths. (-).

Orientation:  $b = a$ ,  $c : a = 2^\circ$  to  $6^\circ$ .

Colorless, yellowish.

Non-pleochroic in thin sections.

$\alpha = 1.796$ ,  $\beta = 1.797$ ,  $\gamma = 1.841$ .

$\gamma - \alpha = 0.045$ ,  $\gamma - \beta = 0.044$ ,  $\beta - \alpha = 0.001$ .

Dispersion: Weak,  $\rho < \nu$ .

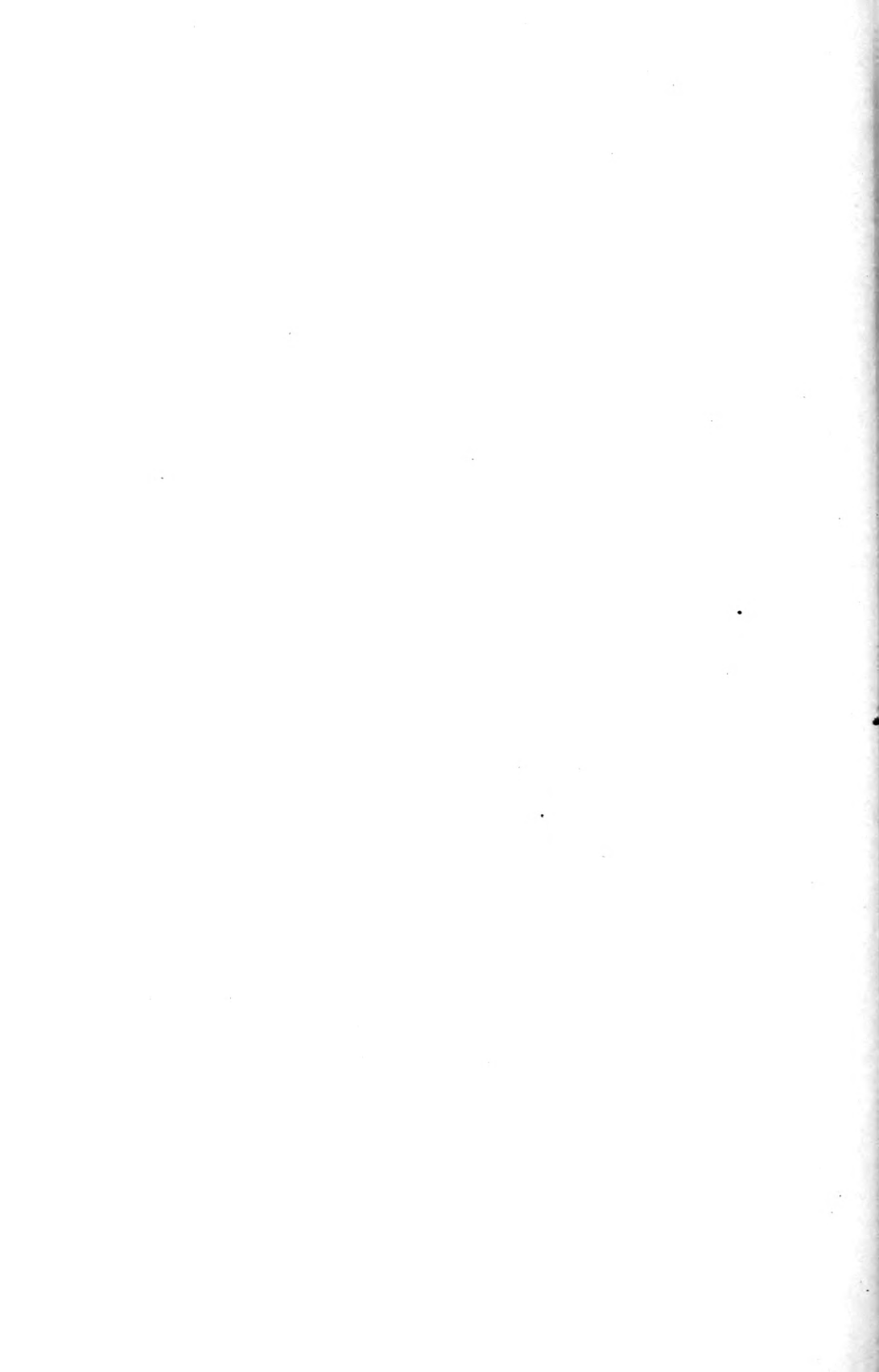
$2E = 21^\circ-36^\circ$ .

Soluble with difficulty in HCl, leaving a white residue.

Olivine has  $2V = 88^\circ$  ca. and contains no P.

Titanite has strong dispersion,  $\rho > \nu$ , contains no P., extinction  $+39^\circ$ , weak pleochroism, and much higher birefringence.

Cut on line.



**Titanite.**— $\text{CaSiTiO}_5$ ,  $H=5.0-5.5$ ,  $G=3.4-3.56$ .

Monoclinic. (+).

Cleavage: (110), distinct.  $(110):(1\bar{1}0)=46^\circ 8'$ .

Habit: Prisms, rhombs, grains, and rods.

Orientation:  $b=\mathfrak{b}$ ,  $c:\mathfrak{c}=+39^\circ$ .

Colorless, yellowish, reddish, brownish.

Pleochroism: Weak,  $\mathfrak{r}>\mathfrak{b}>\mathfrak{a}$ .

$\alpha=1.913$ ,  $\beta=1.921$ ,  $\gamma=2.054$ .

$\gamma-\alpha=0.141$ ,  $\gamma-\beta=0.133$ ,  $\beta-\alpha=0.008$

Dispersion: Very strong,  $\rho>\nu$ .

$2E_{na}=45^\circ-68^\circ$ .

Very slightly affected by HCl.

**Monazite** has lower birefringence, weak dispersion, and low extinction.

**Brookite** has parallel extinction,  $2V=0^\circ-23^\circ$ , and great difference in birefringence in two directions;  $\gamma-\alpha=0.158$ , while  $\beta-\alpha=0.003$ .

**Other minerals:** The very strong double refraction and indices, and the very strong dispersion, separate titanite from other minerals.

**Rutile**, **xenotime**, **hussakite**, and **cassiterite** give no reaction for Ca.

**Brookite.**— $\text{TiO}_2$ ,  $H=5.5-6.0$ ,  $G=3.87-4.01$ .

Orthorhombic. (+).

Cleavage: (010), good, though not always seen microscopically.

Habit: Tabular, plates.

Elongation: (100), narrow laths. ( $\mp$ ).

Orientation:  $a=\mathfrak{r}$ ,  $b=\mathfrak{a}$ , for red;  $a=\mathfrak{r}$ ,  $c=\mathfrak{a}$ , for green. Axial p ane for red and yellow lies in (001), for green and blue in (010).

$\alpha=2.583$ ,  $\beta=2.586$ ,  $\gamma=2.741$ .

$\gamma-\alpha=0.158$ ,  $\gamma-\beta=0.156$ ,  $\beta-\alpha=0.003$ .

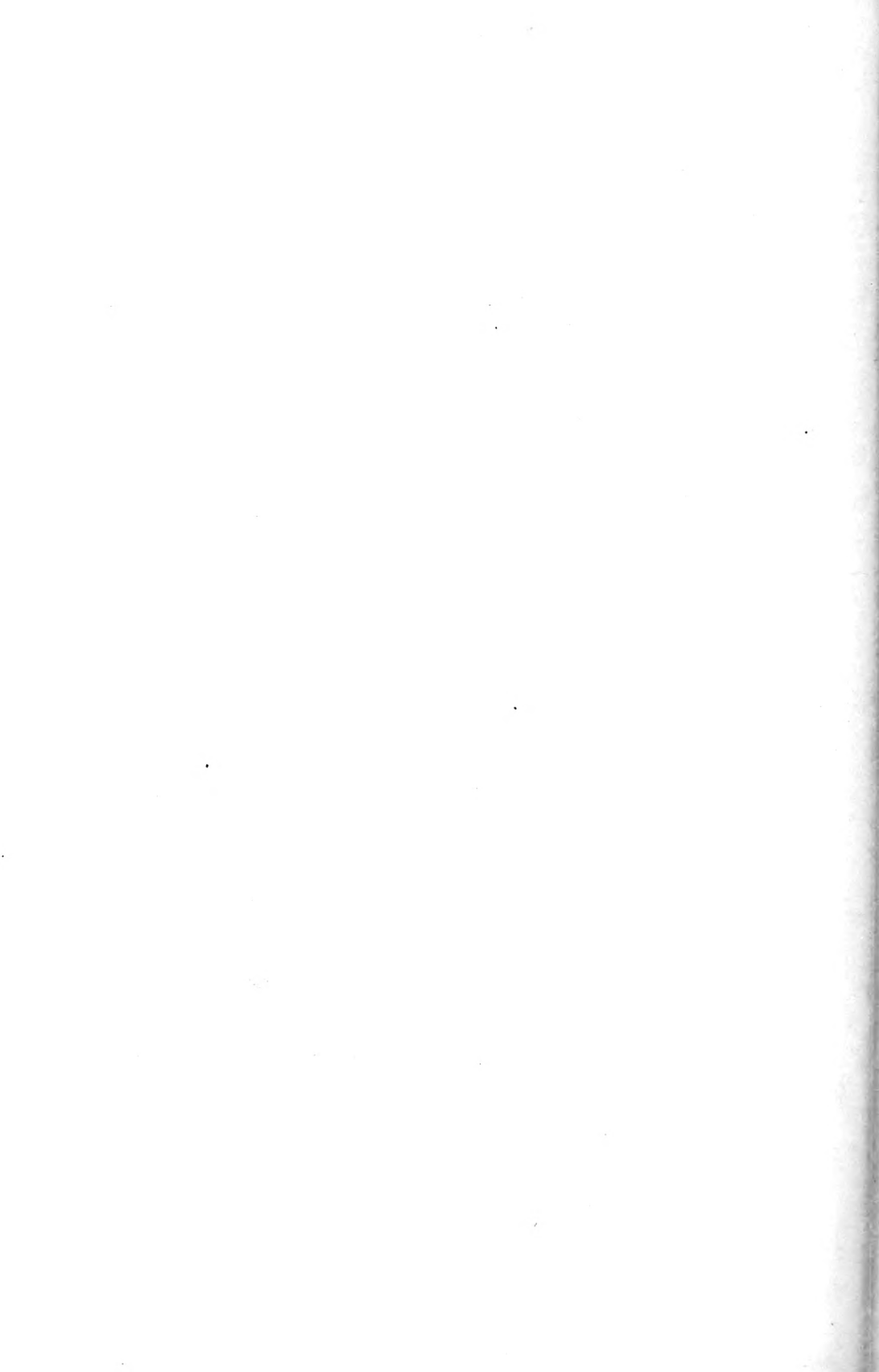
Dispersion:  $\rho>\nu$ .

$2V=0^\circ-23^\circ$ .

Insoluble in acids. Gives Ti reaction.

**Cassiterite** and **rutile** have different habit, and **brookite** has very different strength of double refraction in (100) and (010) sections.

Cut on line.



The mineral is **anisotropic**.

**Parallel** extinction.

**Colored**.

COLORED.

*Cut on line.*



The mineral is **anisotropic**.

**Parallel extinction.**

**Colored.**

**Non-pleochroic.**

**NON-PLEOCHROIC.**

*Cut on line.*





The mineral is **anisotropic**.

**Parallel extinction.**

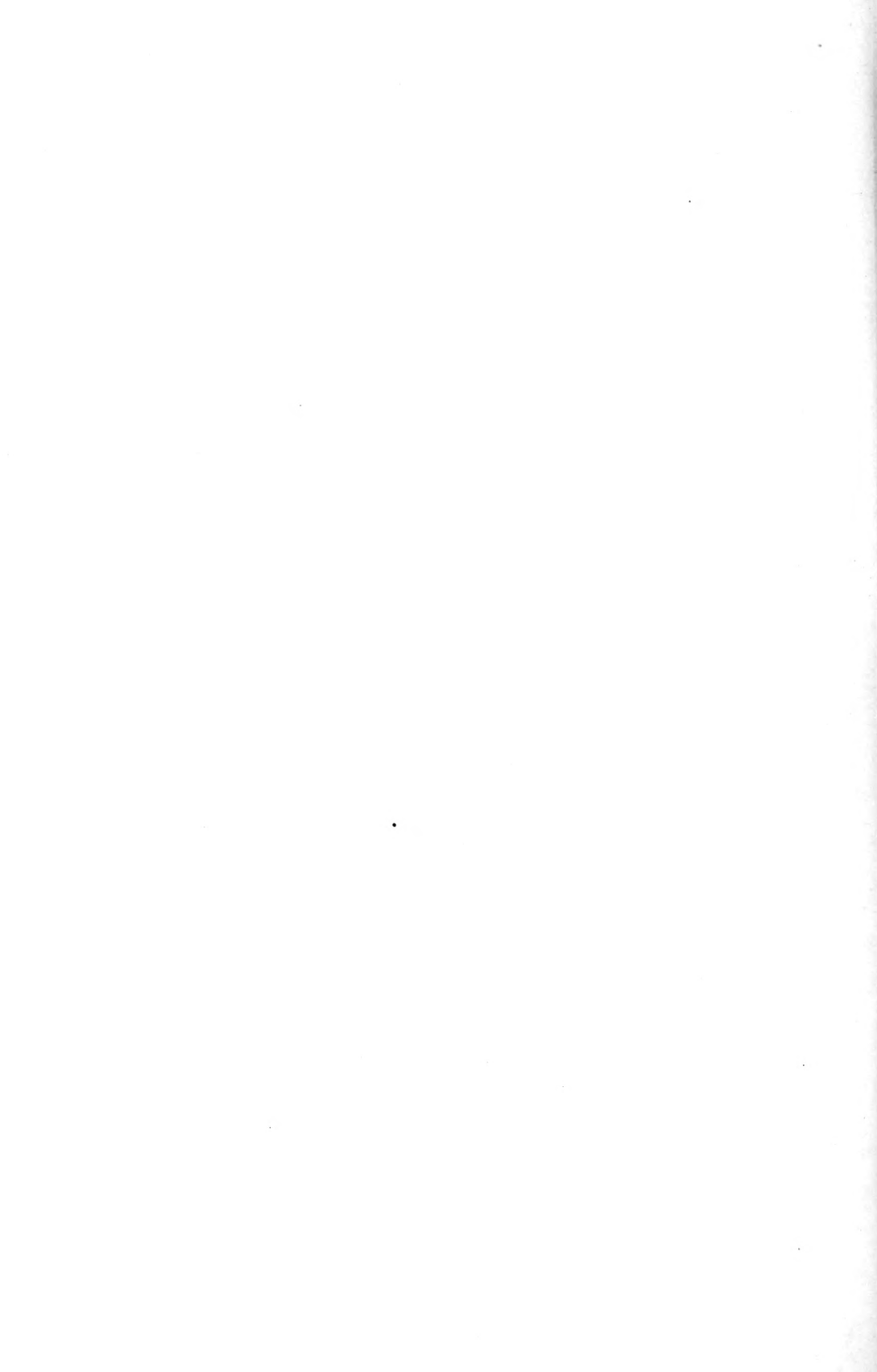
**Colored.**

**Non-pleochroic.**

**Maximum birefringence is less**  
than that of quartz.

BIREFRINGENCE < QUARTZ.

*Cut on line.*



UNIAXIAL.

*Cut on line.*

The mineral is anisotropic.

Parallel extinction.

Colored.

Non-pleochroic.

Maximum birefringence is less  
than that of quartz.

Uniaxial.

The Mineral is ANISOTROPIC, has PARALLEL EXTINCTION, is COLORED, NON-PLEOCHROIC, MAXIMUM BIREFRINGENCE < Quartz, UNIAXIAL.									
The Mineral is NEGATIVE (-).					The Mineral is POSITIVE (+).				
← Increase in Index of Refraction. →									
2.50 2.00 1.90 1.80 1.75	1.70	1.65	1.60	1.55	In- crease BIREFR.	1.55	1.60	1.65	1.70 1.75 1.80 1.90 2.00 2.50
Vary H.	High.	Medium.	Not Marked.			Not Marked.	Medium.	High.	Vary H.
					.001				
					.002		Eudialite.		Garnet. *
		Euclite. =			.003				
		Apatite. =			.004				
		Melilite. =			.005		H		
Vesuvianite.					.006			+	
					.007				
					.008				
					.009				
					.010				

\* Garnets are isotropic but often have anomalous double refraction.

**Eucolite.**— $R^{\text{II}}_3R^{\text{I}}_4\text{Zr}(\text{SiO}_3)_7$ , where  $R^{\text{II}}=\text{Ca}$ , with Fe, Mn, and  $R^{\text{I}}=\text{Na}$  with H and a little K,  $H=5.5-6.5$ ,  $G=3.05$ .

Hexagonal. (—).

Cleavage: (0001), dist net.

Habit: Grains.

Elongation: (0001), short lath-shaped. (+).

Reddish, yellowish, brownish, colorless.

Pleochroism:  $O \succ E$ , rarely  $O < E$ .

$\omega=1.621$ ,  $\varepsilon=1.618$ .

$\omega - \varepsilon = 0.003$ .

Optical anomalies,  $2E$  often up to  $50^\circ$ .

Gelatinizes with HCl and the solution gives reaction for Zr.

**Eudialyte** is optically (+), elongation is (—), and indices and birefringence are both lower.

**Garnets** have much higher indices and are isotropic unless anomalous.

**Tourmaline** has stronger double refraction and strong pleochroism.

**Apatite.**— $\text{CaF} \cdot \text{Ca}_4(\text{PO}_4)_3$  and  $\text{CaCl} \cdot \text{Ca}_4(\text{PO}_4)_3$ ,  $H=5.0$ ,  $G=3.10-3.22$ .

Hexagonal. (—).

Cleavage: (0001), (1010), poor; long prisms often show cross fractures.

Habit: Long prisms, rounded grains, granular aggregates.

Elongation: (1010):(0110), lath-shaped. (—).

Colorless, violet, brownish, reddish, gray.

Absorption:  $E > O$ , in colored crystals.

$\omega=1.638$ ,  $\varepsilon=1.634$ .

$\omega - \varepsilon = 0.004$ .

Anomalous biaxial character in large individuals only.

Easily soluble in  $\text{H}_2\text{SO}_4$ , yellow precipitate with ammonium molybdate.

Easily soluble in  $\text{HNO}_3$ .

**Vesuvianite**, **melilite**, **gehlenite**, **zoisite**, and **tourmaline** are not soluble or have different crystal form or color.

**Tourmaline** has  $O > E$ , while colored apatite has  $E > O$ .

**Melilite.**—Ca, Mg, Fe, Al sil cate,  $H=5.0$ ,  $G=2.9-3.1$ .

Tetragonal. (±).

Cleavage: (001):(110), poor; only basal cleavage generally seen in thin sections, and this occurs as a single cleft exactly in the center of the lath-shaped section.

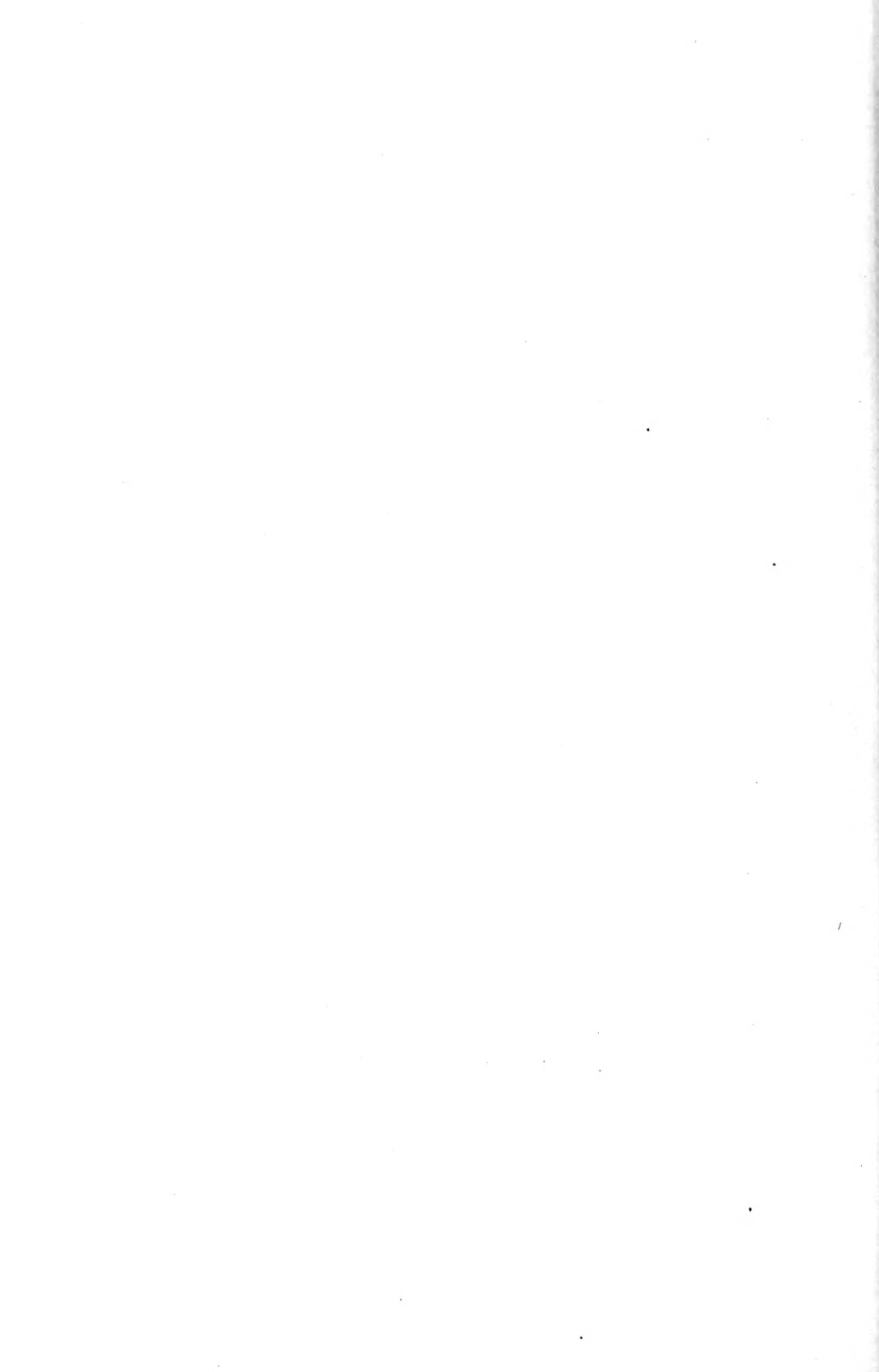
Habit: Plates, short prisms.

Elongation: (001), laths. (±).

Colorless, yellowish.

Pleochroism: None when colorless; for yellow melilite,  $E$ =dark yellow,  $O$ =light yellow.

Cut on line.



$\omega = 1.634$ ,  $\varepsilon = 1.629$ .

$\omega - \varepsilon = 0.005$ ; often unusual indigo-blue interference colors.

Gelatinizes easily with HCl. "Peg" structure and central cleavage crack are characteristic.

**Vesuvianite** and **zoisite** are insoluble in acids.

**Gehlenite** has not the unusual interference colors.

**Vesuvianite**.— $\text{Al}_2(\text{SiO}_4)_3\text{Ca}_6(\text{AlOH})$ ,  $H = 6.5$ ,  $G = 3.35-3.47$ .

Tetragonal. (—, rarely +).

Cleavage: (110), (100), poor.

Habit: Short prisms, grains, dull masses

Elongation: (110):(1 $\bar{1}$ 0), prismatic. (±).

Colorless, yellowish, greenish, reddish, brownish, blue.

Pleochroism: Weak to unnoticeable.

$\omega = 1.705-1.732$ ,  $\varepsilon = 1.701-1.726$ .

$\omega - \varepsilon = 0.006-0.001$ , often abnormal interference colors. Anomalous biaxial character.

Insoluble in acids unless fused to glass.

**Zoisite** has the high indices and weak double refraction found in vesuvianite. The optic angle of zoisite often falls as low as  $0^\circ$ , and vesuvianite has often anomalous double refraction with very variable axial angle. Zoisite, however, has very good pinacoidal cleavage.

**Gehlenite** gelatinizes easily with HCl.

**Andalusite** always has a larger axial angle.

*Cut on line.*





Eudialyte.—Ca, Fe, Mn, Zr, Na silicate,  $H = 5.5-6.5$ ,

$G = 2.92$ .

Hexagonal. (+).

Cleavage: (0001), distinct.

Habit: Rhombs, thick plates.

Elongation: (0001), short lath-shaped. (-).

Reddish, yellowish, brownish, colorless.

Pleochroism:  $O > E$ , weak or wanting.

$\omega = 1.606-1.611$ ,  $\epsilon = 1.610-1.613$ .

$\epsilon - \omega = 0.002$ .

Often anomalous biaxial character,  $2E$  up to  $50^\circ$ .

Gelatinizes with HCl, which, when diluted, gives reaction for Zr.

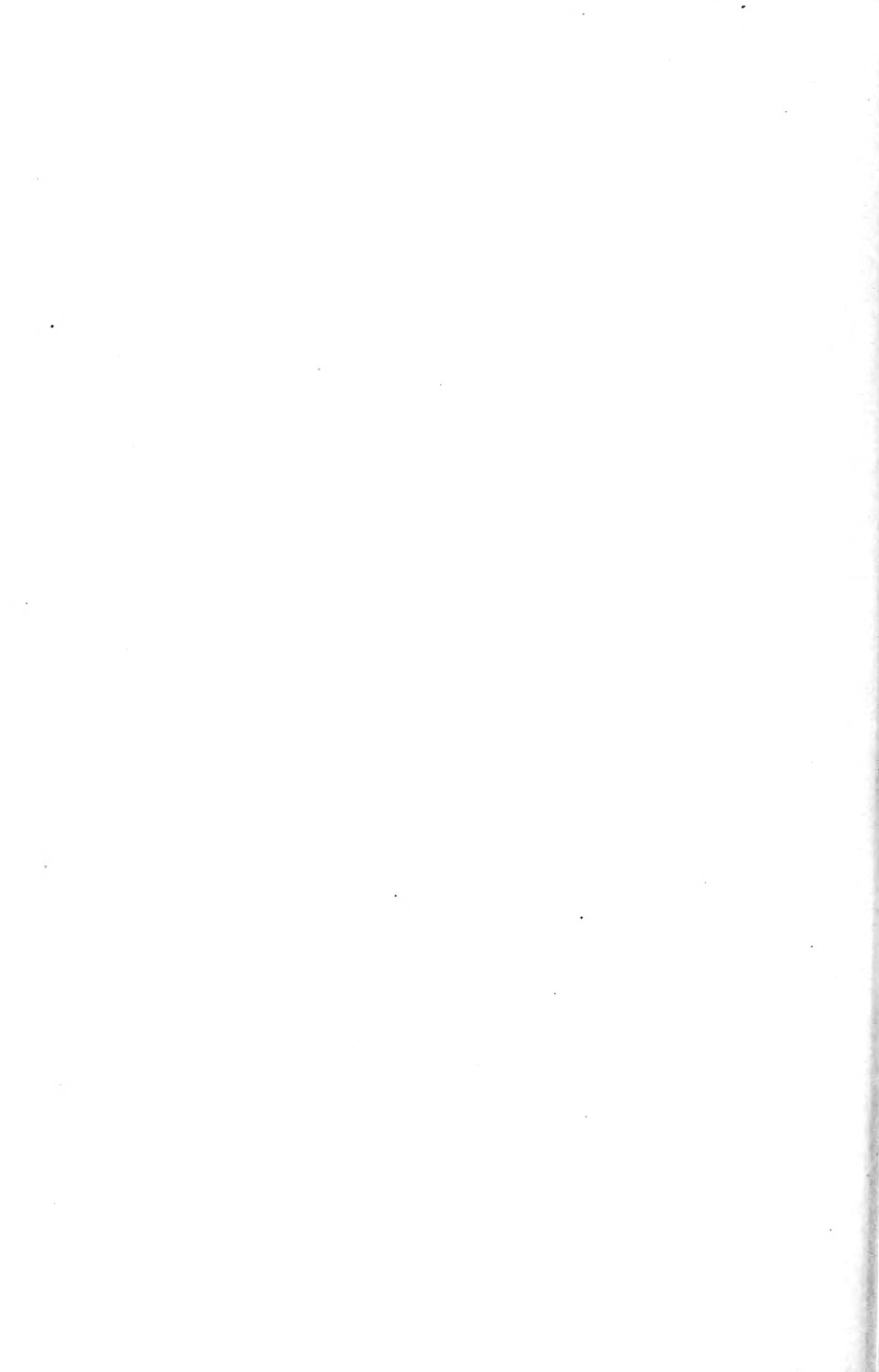
**Garnets** have much higher indices and are isotropic unless anomalous.

**Tourmaline** has stronger double refraction.

**Eucolite** is optically (-), elongation is (+), and indices and double refraction are both higher.

**Garnets.**— Isometric. Belong here only on account of the anomalous double refraction. The crystal form and high indices of refraction make the determination easy. See garnets under isotropic minerals.

*Cut on line.*



The mineral is **anisotropic**.

**Parallel extinction.**

**Colored.**

**Non-pleochroic.**

**Maximum birefringence is less  
than that of quartz.**

**Biaxial.**

**BIAXIAL.**

*Cut on line.*

The Mineral is ANISOTROPIC, has PARALLEL EXTINCTION, is COLORED, NON-PLEOCHROIC, MAXIMUM BIREFRINGENCE < Quartz. BIAxIAL.											
The Mineral is NEGATIVE (-).						The Mineral is POSITIVE (+).					
← Increase in Index of Refraction. →											
1.80 1.75 1.70 1.65 1.60 1.55 1.50	1.70	1.65	1.60	1.55	In crease BIREFR.	1.55	1.60	1.65	1.70	1.75 1.80 1.85 1.90 1.95	2.00
Vary H.	High.	Medium.	Not Marked			Not Marked.	Medium.	High.		Vary H.	
					001						
					002						
					003						
					004						
					005						
					006						
		Lepidolite.			007						
					008					Clinozoisite.	
			Cordierite.		009		Bronzite.		Zoisite. Thulite.		
					010						

**Lepidolite.**— $\text{Al}(\text{SiO}_4)_3\text{Al}_2\text{KLiH} + \text{Al}(\text{Si}_3\text{O}_8)_3\text{K}_3\text{Li}_3(\text{AlF}_2)_3$ ,  $\text{H} = 2.5\text{--}4.0$ ,  
 $\text{G} = 2.8\text{--}2.9$ .

Monoclinic. (−).

Cleavage: (001), good.

Habit: Leaves, leafy aggregates.

Elongation: At right angles to (001), lath-shaped. (+).

Orientation:  $b = c$ ,  $c : a = 0^\circ$  to  $+2^\circ$ ; or rarely  $b = b$ ,  $c : a = 0^\circ$  to  $+2^\circ$ .

Colorless, reddish.

Pleochroism: Weak or none.

$\alpha = ( )$ ,  $\beta = 1.598$ ,  $\gamma = 1.605$ .

$\gamma - \beta = 0.007$ .

Dispersion: Weak,  $\rho \geq \nu$ .

$2E = 32^\circ\text{--}84^\circ$ .

Insoluble in acids.

**Muscovite** and **paragonite** do not give Li flame. See also under muscovite and Part II.

**Cordierite.**— $\text{Mg}_2\text{Al}_4\text{Si}_3\text{O}_{18}$ ,  $\text{H} = 7.0\text{--}7.5$ ,  $\text{G} = 2.59\text{--}2.66$ .

Orthorhombic. (−).

Cleavage: (010), poor.

Habit: Grains, short prisms. Trillings and polysynthetic twins occur.

Elongation: (110), ( $\bar{1}\bar{1}0$ ), short laths. (−).

Orientation:  $b = c$ ,  $c = a$ .

Colorless, bluish, yellowish.

Pleochroism: Wanting or weak with  $b > c > a$ .

$\alpha = 1.535$ ,  $\beta = 1.540$ ,  $\gamma = 1.544$ .

$\gamma - \alpha = 0.009$ ,  $\gamma - \beta = 0.004$ ,  $\beta - \alpha = 0.005$ .

Dispersion: Weak,  $\rho < \nu$ .

$2E = 63^\circ\text{--}150^\circ$ .

When treated with HF gives characteristic prismatic crystals of magnesium fluosilicate.

**Quartz** has higher interference colors, is uniaxial, and (+).

Chemically different, reactions as above.

Cut on line.



**Clinozoisite.**— $\text{Al}(\text{SiO}_4)_3\text{Al}_2\text{Ca}\cdot\text{CaOH}$ ,  $H=6.5$ ,  $G=3.3-3.5$ .

Monoclinic. (+).

Cleavage: (001), good; (100), distinct.

Habit: Prisms and rods elongated on (*b*); grains. Twinning (100).

Elongation: (001):(100), lath-shaped. ( $\pm$ ).

Orientation:  $b = \mathbf{b}$ ,  $c : a = -3^\circ$ .

Colorless, reddish.

Pleochroism: Weak.

$\alpha = 1.716$ ,  $\beta = 1.718$ ,  $\gamma = 1.724$ .

$\gamma - \alpha = 0.008$ ,  $\gamma - \beta = 0.006$ ,  $\beta - \alpha = 0.002$ .

Dispersion: Strong,  $\rho < \nu$ .

$2V = 80^\circ-90^\circ$ .

An iron-poor or iron-free epidote. Pistacite is the iron-rich epidote.

Abnormal interference colors common. Strong dispersion of the bisectrices. Insoluble in HCl.

Zoisite has parallel extinction and smaller value for  $2V$ .

**Bronzite.**— $(\text{Mg}, \text{Fe})_2\text{Si}_2\text{O}_6$ ,  $H=5.0-6.0$ ,  $G=3.29$ .

Orthorhombic. (+).

Cleavage: (010), distinct; (100), good; (110), good. (110):(1 $\bar{1}$ 0) =  $91^\circ 40'$ .

Habit: Prismatic, cloudy masses.

Elongation: (110):(1 $\bar{1}$ 0), lath-shaped. (+).

Orientation:  $b = \mathbf{a}$ ,  $c = \mathbf{c}$ .

Colorless, yellowish, reddish.

Pleochroism: Weak,  $\mathbf{c}$  = greenish,  $\mathbf{a}$  = reddish yellow,  $\mathbf{b}$  = reddish brown.

$\alpha = 1.665$ ,  $\beta = 1.669$ ,  $\gamma = 1.674$ .

$\gamma - \alpha = 0.009$ ,  $\gamma - \beta = 0.005$ ,  $\beta - \alpha = 0.004$ .

Dispersion:  $\rho < \nu$ .

$2E = 106^\circ$  ca.

Geniculated and star-shaped twins.

**Hypersthene** has same pleochroism, strong, and is (−).

**Monoclinic pyroxenes.** See enstatite above and Part II.

**Zoisite.**— $\text{HCa}_2\text{Al}_3\text{Si}_3\text{O}_{13}$ ,  $H=6.0-6.5$ ,  $G=3.25-3.37$ .

Orthorhombic. (+).

Cleavage: (010), good; (100), distinct.

Habit: Rods, leaves.

Elongation: (110):(1 $\bar{1}$ 0), short laths. ( $\pm$ ).

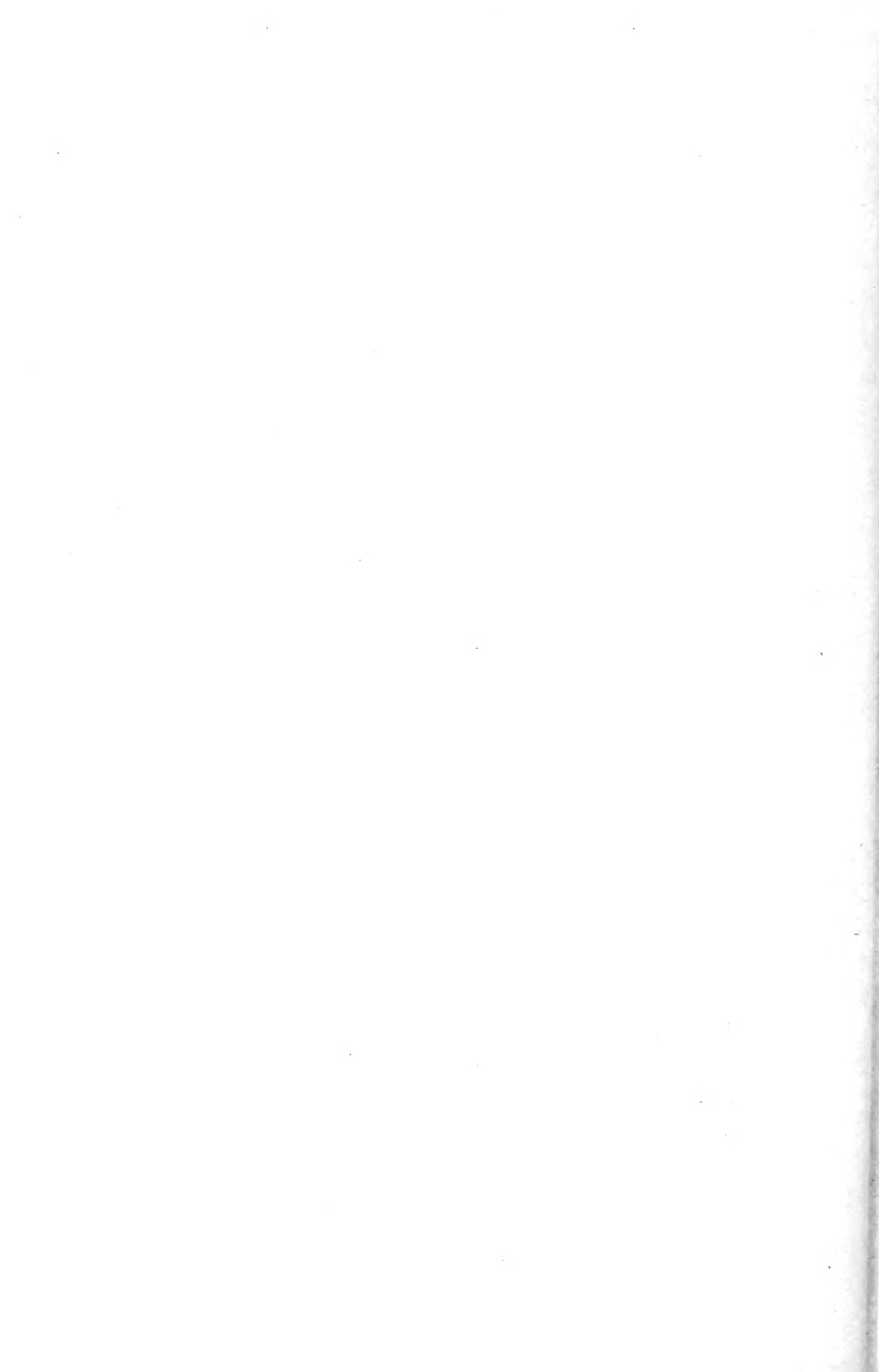
Orientation:  $a = \mathbf{c}$ ,  $c = \mathbf{a}$ ; or  $a = \mathbf{c}$ ,  $b = \mathbf{a}$ .

Colorless

Pleochroism: None in thin sections.

$\alpha = 1.698$ ,  $\beta = 1.699$ ,  $\gamma = 1.707$ .

$\gamma - \alpha = 0.009$ ,  $\gamma - \beta = 0.008$ ,  $\beta - \alpha = 0.001$ .





Dispersion: Strong,  $\rho < \nu$ ,  $\rho > \nu$ .

$2V = 0^\circ - 60^\circ$ .

Insoluble in acids.

Abnormal interference colors.

**Pistacite**, with weak double refraction, is similar when the axial plane is at right angles to the cleavage

**Vesuvianite** has poor cleavage.

**Melilite** gelatinizes with acids.

Thulite.— Manganese zoisite,  $H = 6.0 - 6.5$ ,  $G = 3.124$ .

Orthorhombic. (+).

Cleavage: (100), distinct.

Habit: Rods, leaves.

Elongation: (110):(110), short lath-shaped. ( $\pm$ ).

Orientation:  $a = \epsilon$ ,  $c = \alpha$ .

Red, yellow.

Pleochroism:  $\alpha$  = nearly colorless,  $\epsilon$  = rose,  $\epsilon$  = yellowish.

Index:  $n = 1.702$ .

Birefringence: Like zoisite, 0.009 maximum

Dispersion:  $\rho < \nu$ .

$2V = 0^\circ - 40^\circ$ .

Insoluble in acids.

Abnormal interference colors.

**Other minerals:** Like zoisite

**Zoisite** is non-pleochroic.

*Cut on line.*



The mineral is **anisotropic**.

**Parallel extinction.**

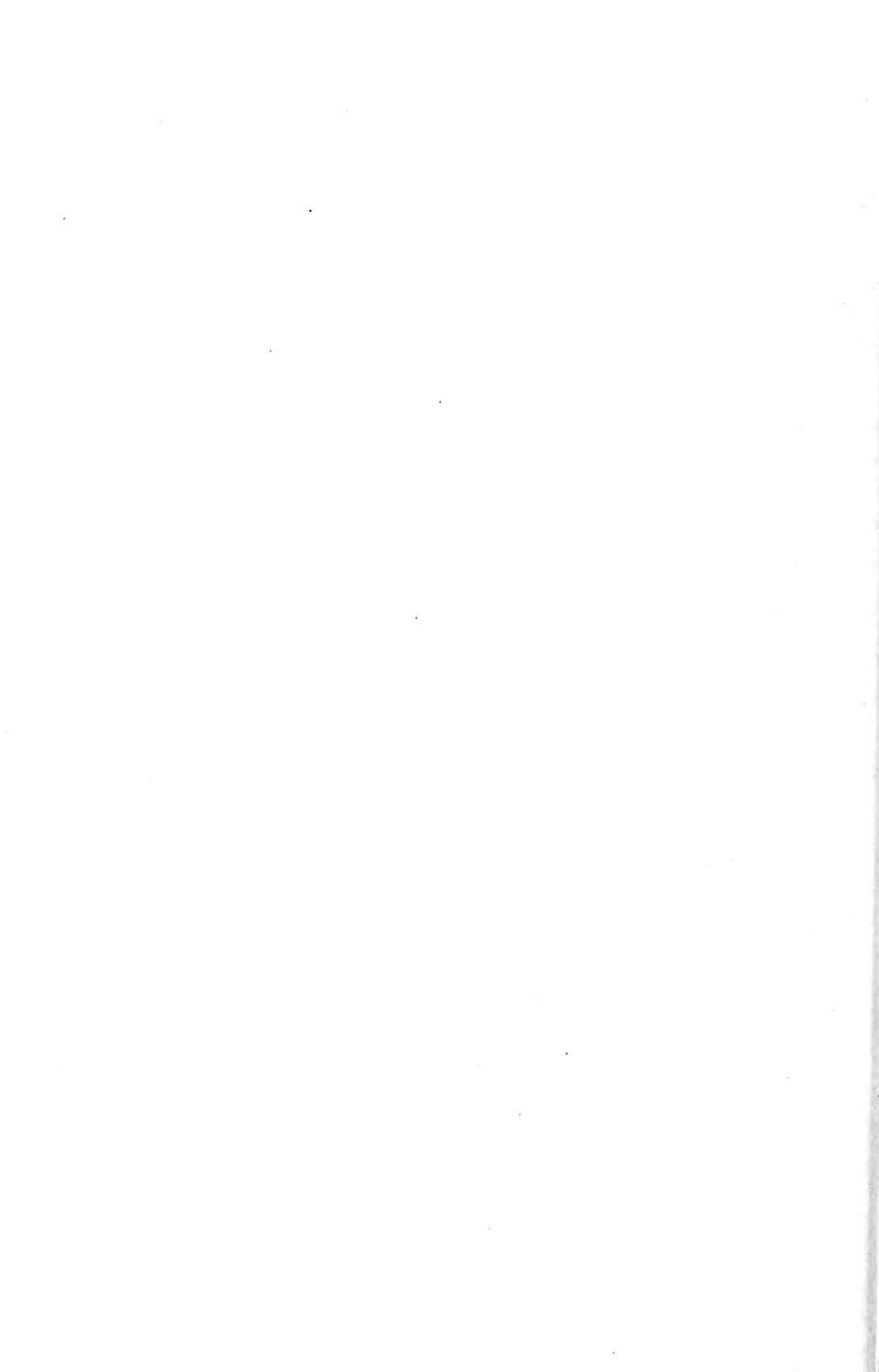
**Colored.**

**Non-pleochroic.**

**Maximum birefringence is greater**  
than that of quartz.

BIREFRINGENCE > QUARTZ.

*Cut on line.*



The mineral is anisotropic.

Parallel extinction.

Colored.

Non-pleochroic.

Maximum birefringence is greater  
than that of quartz.

Uniaxial.

UNIAXIAL.

*Cut on line.*



**Melinophane.**— $\text{NaCa}_2\text{Be}_2\text{Si}_3\text{O}_{10}\text{F}$ ,  $H = 5.0-5.5$ ,  $G = 3.00-3.018$ .

Tetragonal. (—).

Cleavage: (001), poor.

Habit: Tabular, leafy aggregates.

Elongation: (001), lath-shaped. (+).

Yellow.

Pleochroism: Only in thick sections,  $O$  = honey-yellow to brownish yellow;  $E$  = weak greenish yellow.

$\omega = 1.613$ ,  $\varepsilon = 1.593$ .

$\omega - \varepsilon = 0.020$ .

Normally a sharp interference figure; sometimes this separates with  $2E$  as high as  $36^\circ$ .

Insoluble in acids.

**Calcite.**— $\text{CaCO}_3$ ,  $H = 3.0$ ,  $G = 2.714$ .

Hexagonal. (—).

Cleavage: (1011), good.  $(10\bar{1}1):(1101) = 74^\circ 55'$ .

Habit: Grains, granular aggregates, threads, rounded aggregates.

Twinning (0112) common.

Colorless, gray, yellowish, brownish.

Absorption:  $O > E$ .

$\omega = 1.658$ ,  $\varepsilon = 1.486$ .

$\omega - \varepsilon = 0.172$ .

Often incloses rhombs of dolomite and magnesite. Readily soluble in cold  $\text{HCl}$ .

**Aragonite** is biaxial and has different cleavage. See also special tests in Part II.

**Dolomite** has twinning  $(02\bar{2}1)$ . Special tests, see Part II

**Dolomite.**— $\text{MgCaC}_2\text{O}_6$ ,  $H = 3.5-4.0$ ,  $G = 2.85-2.95$ .

Hexagonal. (—).

Cleavage: (1011), good.  $(1011):(1101) = 73^\circ 45'$ .

Habit: Rhombohedrons, granular aggregates. Twins  $(02\bar{2}1)$  occasionally occur.

Colorless, gray, yellowish, brownish.

Absorption:  $O > E$ , strong.

$\omega = 1.682$ ,  $\varepsilon = 1.503$ .

$\omega - \varepsilon = 0.179$ .

Soluble with difficulty in cold acid; easily in hot.

**Calcite** has lower indices and is soluble in acetic acid, twinning (0112). Chemical differences between calcite, dolomite, and aragonite, see Part II.

Cut on line.





**Magnesite.**— $\text{MgCO}_3$ ,

H = 3.5–4.5,

G = 2.9–3.1.

Hexagonal. (–).

Cleavage:  $(10\bar{1}1)$ , good.  $(10\bar{1}1):(\bar{1}101) = 72^\circ 40'$ .

Habit: Rhombohedrons, granular aggregates.

Colorless, yellowish, grayish, brownish.

Absorption:  $O > E$ . $\omega_{na} = 1.717$ ,  $\epsilon_{na} = 1.515$ . $\omega - \epsilon = 0.202$ .

Cold HCl does not act upon magnesite.

Dolomite and calcite are acted upon more readily by acids.

See also special tests in Part II.

*Cut on line.*



**Leucoxene.**—An alteration product of ilmenite.

Habit: Granular; fibrous at right angles to the ilmenite crystal. Yellowish to nearly opaque. By incident light it is white, yellowish, or brownish.

Index: High.

Birefringence: Strong, when transparent enough to be observed.

Other minerals differ in the mode of occurrence, leucoxene being associated with ilmenite.

**Xenotime.**— $\text{YPO}_4$ ,  $\text{H} = 4.0\text{--}5.0$ ,  $\text{G} = 4.45\text{--}4.59$ .

Tetragonal. (+).

Cleavage: (110) good.

Habit: Pyramids, prisms.

Elongation: (110):(110), prismatic. (+).

Colorless, yellowish, light brown.

$\omega$  = high,  $\epsilon$  = high, but lower than zircon.

Birefringence: High.

Optical properties very similar to zircon. Xenotime, which is sulphur free, may be decomposed hussakite, which name would then be unnecessary, since xenotime has priority.

**Monazite** is biaxial.

**Titanite** is harder, has different chemical composition, and is biaxial.

**Anatase** is (−), is harder, and is different chemically.

**Cassiterite** and **rutile** have higher double refraction, are harder, and differ chemically.

**Zircon** is harder, has higher indices of refraction, and differs chemically.

**Zircon.**— $\text{ZrSiO}_4$ ,  $\text{H} = 7.5$ ,  $\text{G} = 4.2\text{--}4.86$ .

Tetragonal. (+).

Cleavage: (110), good; (100), poor.

Habit: Prisms, rarely pyramids, grains.

Elongation: (110):(110), prismatic. (+).

Colorless, seldom yellowish to reddish.

Pleochroism: Weak, not generally noticeable in thin sections.

$\omega = 1.931$ ,  $\epsilon = 1.993$ .

$\epsilon - \omega = 0.0443\text{--}0.0618$ .

Insoluble in acids, except the powder in hot concentrated sulphuric acid.

**Cassiterite** has higher double refraction and different chemical reactions.

**Xenotime** is softer and has lower indices of refraction.

**Hussakite.**— $3\text{P}_2\text{O}_5 \cdot \text{SO}_3 \cdot 3\text{R}_2\text{O}_3$ , where R is Y, Er, Ga,  $\text{H} = 5.0$ ,  $\text{G} = 4.587$ .

Tetragonal. (+).

Cleavage: (110), good.

Habit: Pyramids, prisms, grains.

Cut on line.



Elongation: (110):(1 $\bar{1}$ 0), prismatic. (+).

Colorless, yellowish, brownish.

$\omega = 1.717-1.724$ ,  $\varepsilon = 1.8113-1.8196$ .

$\varepsilon - \omega = 0.0948$ .

Insoluble in acids.

The  $\text{SO}_2$  free xenotime may be decomposed hussakite; if so the name xenotime has priority.

**Zircon** has lower double refraction and contains neither  $\text{P}_2\text{O}_5$  nor Y.

**Cassiterite** has higher indices and contains neither  $\text{P}_2\text{O}_5$  nor Y.

**Cassiterite.**— $\text{SnO}_2$ ,  $\text{H} = 6.0-7.0$ ,  $\text{G} = 6.8-7.1$ .

Tetragonal. (+).

Cleavage: (110), poor; (100), distinct.

Habit: Grains, prisms, rods, pyramids, twins.

Elongation: (110):(110), prismatic. (+).

Yellowish, brownish, colorless.

Pleochroism: Very weak, generally not observable in thin sections.

$\omega = 1.997$ ,  $\varepsilon = 2.093$ .

$\varepsilon - \omega = 0.096$ .

Optical anomalies, rare and weak.

Insoluble in acids.

**Rutile** has higher double refraction and better cleavage.

**Anatase** is (-).

**Brookite** and **pseudobrookite** are biaxial.

**Perovskite** and **zircon** and all the above differ chemically and in having lower specific gravities than cassiterite.

**Rutile.**— $\text{TiO}_2$ ,  $\text{H} = 6.0-6.5$ ,  $\text{G} = 4.2-4.3$ .

Tetragonal. (+).

Cleavage: (110), (100), good to fair.

Habit: Prisms, grains, geniculated and heart-shaped twins, sagenite webs.

Elongation: (110):(1 $\bar{1}$ 0), prismatic. (+).

Yellow, fox-red, violet.

Pleochroism: Seldom noticeable,  $O$ =yellow to brownish,  $E$ =brownish yellow to greenish yellow.

$\omega = 2.616$ ,  $\varepsilon = 2.903$ .

$\varepsilon - \omega = 0.2871$ .

Insoluble in acids.

**Cassiterite** and **zircon** have lower double refraction and different chemical reactions.

**Anatase**, **brookite**, and **pseudobrookite** differ in crystal form and cleavage and have lower birefringence.

**Perovskite** contains Ca and is generally isotropic.

Cut on line.



The mineral is anisotropic.

Parallel extinction.

Colored.

Non-pleochroic.

Maximum birefringence is greater  
than that of quartz.

Biaxial.

BIAXIAL.

*Cut on line.*





**Delessite**— $\text{H}_{10}(\text{Mg}, \text{Fe})_4(\text{Al}, \text{Fe})_2\text{Si}_4\text{O}_{23}$ ,  $\text{H}=2.5$ ,  $\text{G}=2.5\text{--}3.0$ .

Monoclinic. (—).

Cleavage: (001), good.

Habit: Scales, spherulitic aggregates.

Elongation: At right angles to (001), lath-shaped. (+).

Orientation:  $b = \mathfrak{b}$ ,  $c: a$  = very small to  $0^\circ$ .

Green, yellow, brown.

Pleochroism:  $a$  = yellowish to colorless,  $c$  and  $\mathfrak{b}$  = green.

Index: Similar to clinocllore. ( $\alpha = 1.585$ ,  $\beta = 1.586$ ,  $\gamma = 1.596$ .)

Birefringence: Similar to clinocllore. ( $\gamma - \alpha = 0.011$ ,  $\gamma - \beta = 0.010$ ,  $\beta - \alpha = 0.001$ .)

Gelatinizes easily with acids.

Clinocllore is (+).

**Other minerals:** Its resemblance to chlorite separates delessite from other minerals.

**Antigorite**.— $\text{H}_4(\text{Mg}, \text{Fe})_3\text{Si}_2\text{O}_9$ ,  $\text{H}=2.5$ ,  $\text{G}=2.622$ .

Orthorhombic. (—).

Habit: Lamellar, leaves, scales.

Elongation: At right angles to (100), lath-shaped. (+).

Orientation:  $a = \mathfrak{a}$ ,  $b = \mathfrak{b}$ .

Greenish, colorless, yellowish.

Non-pleochroic.

$\alpha = 1.560$ ,  $\beta = 1.570$ ,  $\gamma = 1.571$ .

$\gamma - \alpha = 0.011$ ,  $\gamma - \beta = 0.001$ ,  $\beta - \alpha = 0.010$ .

Dispersion:  $\rho > \nu$ .

$2E = 16^\circ\text{--}98^\circ$ .

In boiling  $\text{HCl}$  silica separates.

Pennine is pleochroic, the double refraction is lower, and the indices are higher.

Ordinary serpentine is (+).

**Bastite**.—Serpentine pseudomorph after an orthorhombic pyroxene,

$\text{H}=3.5\text{--}4.0$ ,  $\text{G}=2.6\text{--}2.8$ .

Orthorhombic. (—).

Cleavage: (100), good.

Habit: Leaves.

Elongation: (110), ( $1\bar{1}0$ ), lath-shaped. (+).

Orientation:  $a = \mathfrak{a}$ ,  $c = \mathfrak{c}$ .

Greenish, yellowish, colorless.

Pleochroism: Weak or wanting.

Index: 1.5–1.6.

Birefringence: Weak.

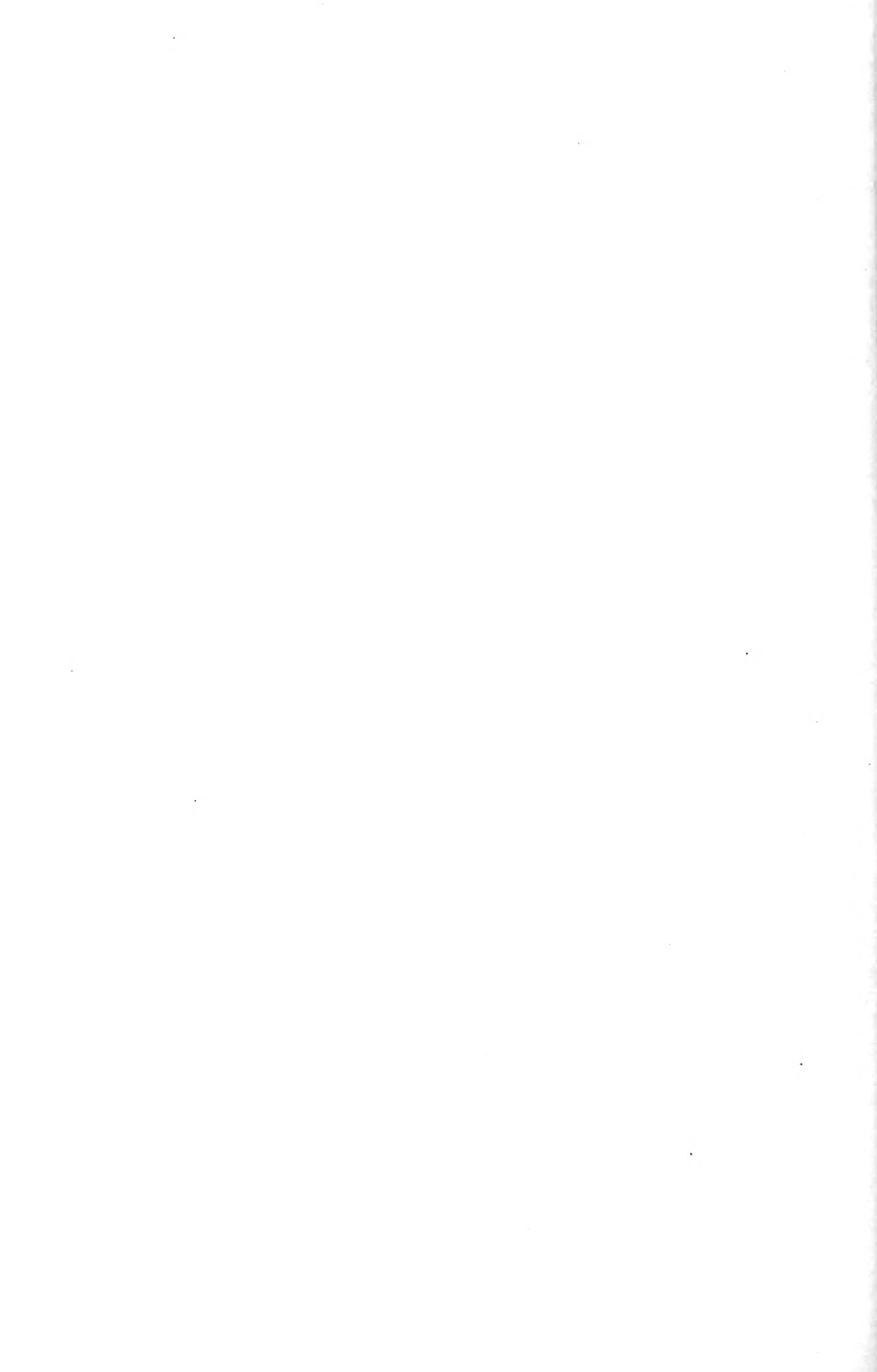
Dispersion:  $\rho > \nu$ .

$2E = 20^\circ\text{--}90^\circ$ .

Gelatinizes more or less easily with acids.

**Other pyroxenes** differ in orientation. See Part II.

*Cut on line.*



**Hypersthene.**— $(\text{Fe}, \text{Mg})\text{SiO}_3$ ,  $H = 5.0-6.0$ ,  $G = 3.40-3.50$ .

Orthorhombic. (—).

Cleavage: (010), distinct; (100), good; (110), good.  $(110):(1\bar{1}0) = 91^\circ 40'$ .

Habit: Prismatic, often massive.

Elongation:  $(110):(1\bar{1}0)$ , lath-shaped. (+).

Orientation:  $b = a$ ,  $c = c$ .

Colorless, yellowish, reddish.

Pleochroism:  $c$  = greenish,  $a$  = reddish yellow,  $b$  = reddish brown.

Strong.

$\alpha = 1.692$ ,  $\beta = 1.702$ ,  $\gamma = 1.705$ .

$\gamma - \alpha = 0.013$ ,  $\gamma - \beta = 0.003$ ,  $\beta - \alpha = 0.010$ .

Dispersion:  $\rho > \nu$ .

$2E = 85^\circ$  ca.

Partially decomposed by HCl.

**Bronzite** is (+) and has weaker pleochroism.

**Monoclinic pyroxenes** have inclined extinction and higher double refraction. Basal sections showing cleavage give the emergence of an axis, while orthorhombic pyroxenes show the emergence of a positive bisectrix. See also Part II.

**Ægirite** has different pleochroism, green to yellowish green, has higher double refraction, and has (—) elongation.

**Prismatine.**— $\text{MgAl}_2\text{SiO}_6$  ca.,  $H = 6.5$ ,  $G = 3.341$ .

Orthorhombic. (—).

Cleavage: (110), distinct,  $(110):(1\bar{1}0) = 81^\circ 31'$ .

Habit: Prismatic.

Elongation:  $(110):(1\bar{1}0)$ , lath-shaped.

Orientation:  $b = c$ ,  $c = a$ .

Yellowish.

Pleochroism: Very weak.

$\alpha = 1.669$ ,  $\beta = 1.681$ ,  $\gamma = 1.682$ .

$\gamma - \alpha = 0.013$ ,  $\gamma - \beta = 0.001$ ,  $\beta - \alpha = 0.012$ .

Dispersion: Weak,  $\rho > \nu$ .

$2E = 65.5^\circ$ .

**Topaz** has good (001) cleavage.

**Andalusite** has a larger axial angle and is pleochroic.

**Cedrite.**— $(\text{Mg}, \text{Fe})\text{SiO}_3$  and  $(\text{Mg}, \text{Fe})\text{Al}_2\text{SiO}_6$ ,  $H = 5.5-6.0$ ,  $G = 3.1-3.2$ .

Orthorhombic. (—).

Cleavage: (110), good; (100), distinct; (010), poor.  $(110):(1\bar{1}0) = 55^\circ 12'$ .

Habit: Rods, leaves, grains.

Elongation:  $(110):(1\bar{1}0)$ , lath-shaped. (+).

Orientation:  $a = a$ ,  $c = c$ .



Colorless, yellowish, brownish, greenish.

Pleochroism:  $\epsilon$ =yellowish, greenish;  $\eta$ =clove-brown, reddish;

$\alpha$ =yellowish, greenish, colorless.

$\alpha=1.623$ ,  $\beta=1.636$ ,  $\gamma=1.644$ .

$\gamma-\alpha=0.021$ ,  $\gamma-\beta=0.008$ ,  $\beta-\alpha=0.013$ .

Dispersion:  $\rho > \nu$ .

$2V=79^\circ-57^\circ$ .

Not affected by acids.

One of the orthorhombic pyroxenes.

Other amphiboles, see Part II.

**Muscovite.**— $\text{Al}(\text{SiO}_4)_3\text{KH}_2\text{Al}_2$ ,  $H=2.0-2.5$ ,  $G=2.8-2.9$ .

Monoclinic. (—).

Cleavage: (001), good.

Habit: Leaves, leafy aggregates.

Elongation: Perpendicular to (001), lath-shaped. (+).

Orientation:  $b=\epsilon$ ,  $c:\alpha=+0^\circ$  to  $+2^\circ$ .

Colorless, greenish, yellowish.

Pleochroism: Weak or wanting.

$\alpha=1.563$ ,  $\beta=1.598$ ,  $\gamma=1.601$ .

$\gamma-\alpha=0.038$ ,  $\gamma-\beta=0.003$ ,  $\beta-\alpha=0.035$ .

Dispersion: Weak,  $\rho > \nu$ .

$2E=60^\circ-70^\circ$ .

Insoluble in HCl and  $\text{H}_2\text{SO}_4$ .

One of the mica group.

**Micas** can only be confused with other minerals having complete basal cleavage. The birefringence, very low in basal sections and high in sections showing cleavage, is very characteristic of them.

**Chlorites** have weak double refraction.

**Talc** has  $2E=6^\circ-20^\circ$ .

**Biotite** has  $2E$  generally much smaller, also  $b=\eta$ .

**Lepidolite** and **paragonite** may be separated by flame test for Li and treatment with HF, by which muscovite will give many crystals of  $\text{K}_2\text{SiF}_6$  and few  $\text{Na}_2\text{SiF}_6$ .

**Paragonite.**— $\text{Al}(\text{SiO}_4)_3\text{Al}_2\text{NaH}_2$ ,  $H=2.0-2.5$ ,  $G=2.8-2.9$ .

Monoclinic. (—).

Cleavage: (001), good.

Habit: Leaves, leafy aggregates.

Elongation: Perpendicular to (001), lath-shaped. (+).

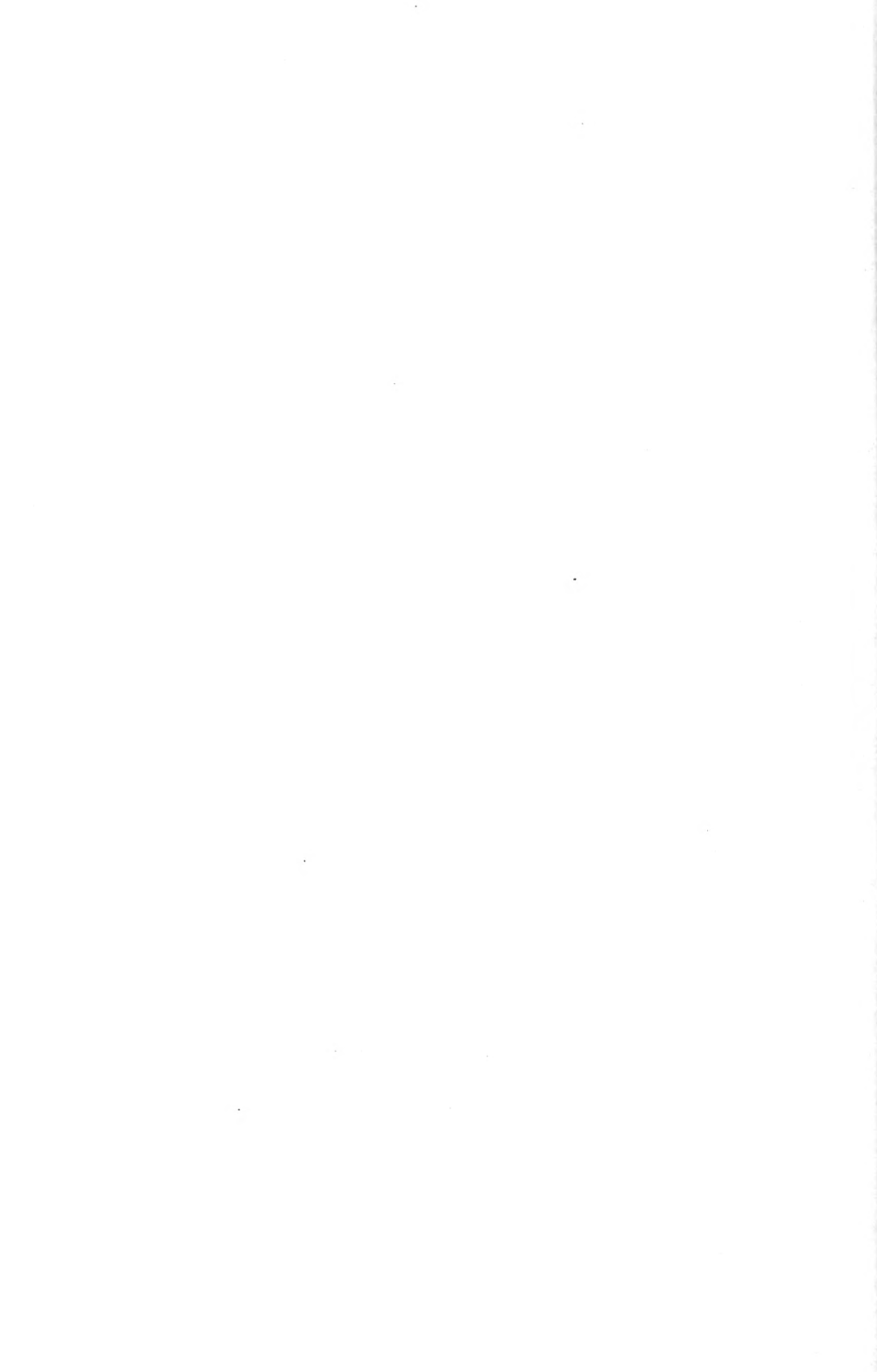
Orientation:  $b=\epsilon$ ,  $c:\alpha=0^\circ$  to  $+2^\circ$ .

Colorless, greenish, yellowish.

Pleochroism: Weak or none.

Indices: Very similar to muscovite, see above.

Birefringence: Like muscovite, see above.



Dispersion: Weak,  $\rho > \nu$ .

$2E = 70^\circ$  ca.

Insoluble in acids.

One of the mica group.

**Muscovite** and **lepidolite** are different chemically.

**Talc** has  $2E = 6^\circ - 20^\circ$ .

**Phlogopite**.—A magnesium mica, near biotite, but containing little Fe,

$H = 2.5 - 3.0$ ,

$G = 2.78 - 2.85$ .

Monoclinic. (—).

Cleavage: (001), good.

Habit: Leaves, leafy aggregates.

Elongation: At right angles to (001), lath-shaped. (+).

Orientation:  $b = \mathbf{b}$ ,  $c : \mathbf{a} = 0^\circ$  to  $+7^\circ$ .

Colorless, yellowish, brownish, greenish.

Pleochroism: Weak with  $\mathbf{r} > \mathbf{b} > \mathbf{a}$ .

$\alpha = 1.562$ ,  $\beta = 1.606$ ,  $\gamma = 1.606$ .

$\gamma - \alpha = 0.044$ ,  $\gamma - \beta = 0.0$ ,  $\beta - \alpha = 0.044$ .

Dispersion: Weak,  $\rho < \nu$ .

$2E$  small to  $0^\circ$ .

Completely decomposed by  $H_2SO_4$ , leaving the silica in thin flakes. One of the micas.

**Other micas**: Phlogopite has small to very small  $2V$ , and has symmetrical position of the plane of the optic axes. See muscovite; also Part II.

**Fayalite**.— $Fe_2SiO_4$ ,

$H = 6.5 - 7.0$ ,

$G = 4.1$ .

Orthorhombic. (—).

Cleavage: (100), poor.

Habit: Isometric, short prisms, grains.

Orientation:  $a = \mathbf{r}$ ,  $b = \mathbf{a}$ .

Greenish, yellowish, red, colorless.

Pleochroism: Wanting or weak in yellow and red tones.

$\alpha = 1.824$ ,  $\beta = 1.864$ ,  $\gamma = 1.874$ .

$\gamma - \alpha = 0.050$ ,  $\gamma - \beta = 0.010$ ,  $\beta - \alpha = 0.040$ .

Dispersion: Distinct,  $\rho > \nu$ .

$2V = 50^\circ$  ca.

An iron-rich olivine.

Gelatinizes quite easily with  $HCl$ .

**Olivine** has  $2V = 88^\circ$ , is (+), and has lower birefringence.

**Forsterite** is (+), has  $2V = 86^\circ$ , lower indices, and is of different occurrence.

**Monticellite** has  $2V = 37.5^\circ$ , lower indices, and lower double refraction.





**Talc.**—  $\text{H}_2\text{Mg}_3\text{Si}_4\text{O}_{12}$ ,  $\text{H} = 1.0$ ,  $\text{G} = 2.7\text{--}2.8$ .  
 Orthorhombic. (—).  
 Cleavage: (001), good.  
 Habit: Leaves, scales.  
 Elongation: At right angles to (001), lath-shaped. (+).  
 Orientation:  $b = \mathbf{c}$ ,  $c = \mathbf{a}$ .  
 Colorless, greenish, bluish.  
 Non-pleochroic.  
 $\alpha = 1.539$ ,  $\beta = 1.589$ ,  $\gamma = 1.589$ .  
 $\gamma - \alpha = 0.050$ ,  $\gamma - \beta = 0.000$ ,  $\beta - \alpha = 0.050$ .  
 Dispersion: Distinct,  $\rho > \nu$ .  
 $2E = 6^\circ\text{--}20^\circ$ .

Hardly affected by acids.

**Brucite** is (+), uniaxial, and has lower double refraction.

**Muscovite** cannot be separated optically when it has a small value for  $2E$ ; it must be separated by testing for the alkalis or with cobalt solution.

*Cut on line.*



**Bronzite.**— $(\text{Mg, Fe})_2\text{Si}_2\text{O}_6$ ,  $H = 5.0-6.0$ ,  $G = 3.29$ .

Orthorhombic. (+).

Cleavage: (010), distinct; (100), good; (110), good.  $(110):(110) = 91^\circ 40'$ .

Habit: Prismatic, cloudy masses. Genuiculated and star-shaped twins occur rarely.

Elongation:  $(110):(110)$ , lath-shaped. (+).

Orientation:  $b = a$ ,  $c = c$ .

Colorless, yellowish, reddish.

Pleochroism: Weak;  $r$  = greenish,  $a$  = reddish yellow,  $b$  = reddish brown.

$\alpha = 1.665$ ,  $\beta = 1.669$ ,  $\gamma = 1.674$ .

$\gamma - \alpha = 0.009$ ,  $\gamma - \beta = 0.005$ ,  $\beta - \alpha = 0.004$ .

Dispersion:  $\rho < \nu$ .

$2E = 106^\circ$  ca.

An orthorhombic pyroxene.

**Hypersthene** has the same pleochroism, strong, and is (-).

**Monoclinic pyroxenes**, see enstatite above, also Part II.

**Zoisite.**— $\text{HCa}_2\text{Al}_3\text{Si}_3\text{O}_{13}$ ,  $H = 6.0-6.5$ ,  $G = 3.25-3.37$ .

Orthorhombic. (+).

Cleavage: (010), good; (100), distinct.

Habit: Rods, leaves.

Elongation:  $(110):(110)$ , short laths. ( $\pm$ ).

Orientation:  $a = r$ ,  $c = a$ ; or  $a = r$ ,  $b = a$ .

Colorless or pale bluish green.

Pleochroism: None in thin sections.

$\alpha = 1.698$ ,  $\beta = 1.699$ ,  $\gamma = 1.707$ .

$\gamma - \alpha = 0.009$ ,  $\gamma - \beta = 0.008$ ,  $\beta - \alpha = 0.001$ .

Dispersion: Strong,  $\rho < \nu$ ,  $\rho > \nu$ .

$2V = 0^\circ-60^\circ$ .

Insoluble in acids.

Abnormal interference colors.

**Pistacite**, with weak double refraction, is similar when the axial plane is at right angles to the cleavage.

**Vesuvianite** has poor cleavage.

**Melilite** gelatinizes with acids.

**Thulite.**—Manganese zoisite,  $H = 6.0-6.5$ ,  $G = 3.124$ .

Orthorhombic. (+).

Cleavage: (100), distinct.

Habit: Rods, leaves.

Elongation:  $(110):(110)$ , short lath-shaped. ( $\pm$ ).

Orientation:  $a = r$ ,  $c = a$ .

Red, yellow.

Cut on line.



Pleochroism: **a**=nearly colorless, **b**=rose, **c**=yellowish.

Index:  $n=1.702$ .

Birefringence: Like zoisite, 0.009 max.

Dispersion:  $\rho < \nu$ .

$2V=0^\circ$  to  $40^\circ$ .

Insoluble in acids.

Abnormal interference colors.

**Other minerals:** Like zoisite.

**Zoisite** is non-pleochroic.

Mosandrite. } Ti, Zr, Th, Ce, Y, Al, Fe, Mn, Ca, Mg, Na, K, F silicate,  
Johnstrupite. } H=4.0 and more, G=3.10-3.29 (Johnst.), 2.93-3.07 (Mosan.)

Monoclinic. (+).

Cleavage: (100), good.

Habit: Tablets (100); elongated on *c*. Twinning (100) frequent.

Elongation: (100):(010), lath-shaped. (-).

Orientation:  $b=\mathbf{b}$ ,  $c:\mathbf{a}=3^\circ$ .

Grayish yellow to colorless.

Pleochroism: Not seen in thin sections.

$\alpha=1.646$ ,  $\beta=1.649$ ,  $\gamma=1.658$ .

$\gamma-\alpha=0.012$ ,  $\gamma-\beta=0.009$ ,  $\beta-\alpha=0.003$ .

Dispersion: Strong  $\rho > \nu$ .

$2V=70^\circ$ .  $2E_{\mathbf{a}}=128^\circ 37'$ .

Soluble in HCl with separation of  $\text{SiO}_2$ ; the dark-red solution on heating gives off Cl, and becomes yellowish.

**Rinkite** has strong  $\rho < \nu$  dispersion, and the position of the plane of the optic axes is not symmetrical.

**Serpentine.**— $\text{H}_4(\text{Mg,Fe})_3\text{Si}_2\text{O}_9$ , H=3.0-4.0,

G=2.5-2.7.

Probably orthorhombic. (+).

Habit: Threads, leaves, aggregates, massive, pseudomorphs.

Elongation: (110):(110), thread-like. (+).

Orientation:  $b=\mathbf{a}$ ,  $c=\mathbf{c}$ .

Green, yellow, colorless.

Pleochroism: Very feeble.

Index:  $n=1.54$  ca.

$\gamma-\alpha=0.013$ .

Dispersion:  $\rho > \nu$ .

$2E=16^\circ-50^\circ$ .

Soluble with separation of gelatinous silica in boiling HCl or  $\text{H}_2\text{SO}_4$ .

**Pennine**, when optically (-), separated by optical character; when (+), by chemical test for  $\text{Al}_2\text{O}_3$ . It has lower birefringence and is pleochroic.

Cut on line.



**Sillimanite.**— $\text{Al}_2\text{SiO}_5$ ,  $H = 6.0-7.0$ ,  $G = 3.23-3.248$ .

Orthorhombic. (+).

Cleavage: (100), good.

Habit: Prisms, threads.

Elongation: (110):(1 $\bar{1}$ 0), long laths. (+).

Orientation:  $b = a$ ,  $c = c$ .

Colorless, yellowish, cloudy.

Pleochroism: Not seen in thin sections.

$\alpha = 1.660$ ,  $\beta = 1.661$ ,  $\gamma = 1.682$ .

$\gamma - \alpha = 0.022$ ,  $\gamma - \beta = 0.021$ ,  $\beta - \alpha = 0.001$ .

Dispersion: Strong,  $\rho > \nu$ .

$2V = 31^\circ-42^\circ$ .

Insoluble in acids.

**Andalusite** is (−), and has (−) elongation, double refraction is lower, and relation of axial plane to cleavage is different.

**Scapolites** are (−), have (−) elongation, and are uniaxial.

**Zoisite** has weaker double refraction and has different orientation.

**Anthophyllite.**— $(\text{Mg,Fe})\text{SiO}_3$ ,  $H = 5.5-6.0$ ,  $G = 3.1-3.2$ .

Orthorhombic. ( $\pm$ ).

Cleavage: (110), good; (100), distinct; (010), poor. (110):(1 $\bar{1}$ 0) =  $54^\circ 23'$ .

Habit: Rods, leaves, grains.

Elongation: (110):(1 $\bar{1}$ 0), lath-shaped. (+).

Orientation:  $a = a$ ,  $c = c$ .

Colorless, yellowish, brownish, greenish.

Pleochroism:  $c$  = yellowish, brownish;  $b$  = clove-brown, reddish;  $a$  = yellowish, greenish, colorless.

$\alpha = 1.633$ ,  $\beta = 1.642$ ,  $\gamma = 1.657$ .

$\gamma - \alpha = 0.024$ ,  $\gamma - \beta = 0.015$ ,  $\beta - \alpha = 0.009$ .

Dispersion:  $\rho < \nu$ ,  $\rho > \nu$ .

$2V \geq 90^\circ$ .

Not noticeably affected by acids.

A member of the amphibole group.

**Amphiboles and pyroxenes**, see Part II.

**Humite.**— $\text{Mg}_3[\text{Mg}(\text{F,OH})_2(\text{SiO}_4)_3]$ ,  $H = 6.5$ ,  $G = 3.1-3.2$ .

Orthorhombic. (+).

Cleavage: (001), distinct.

Habit: Grains. Twins. Often lamellar.

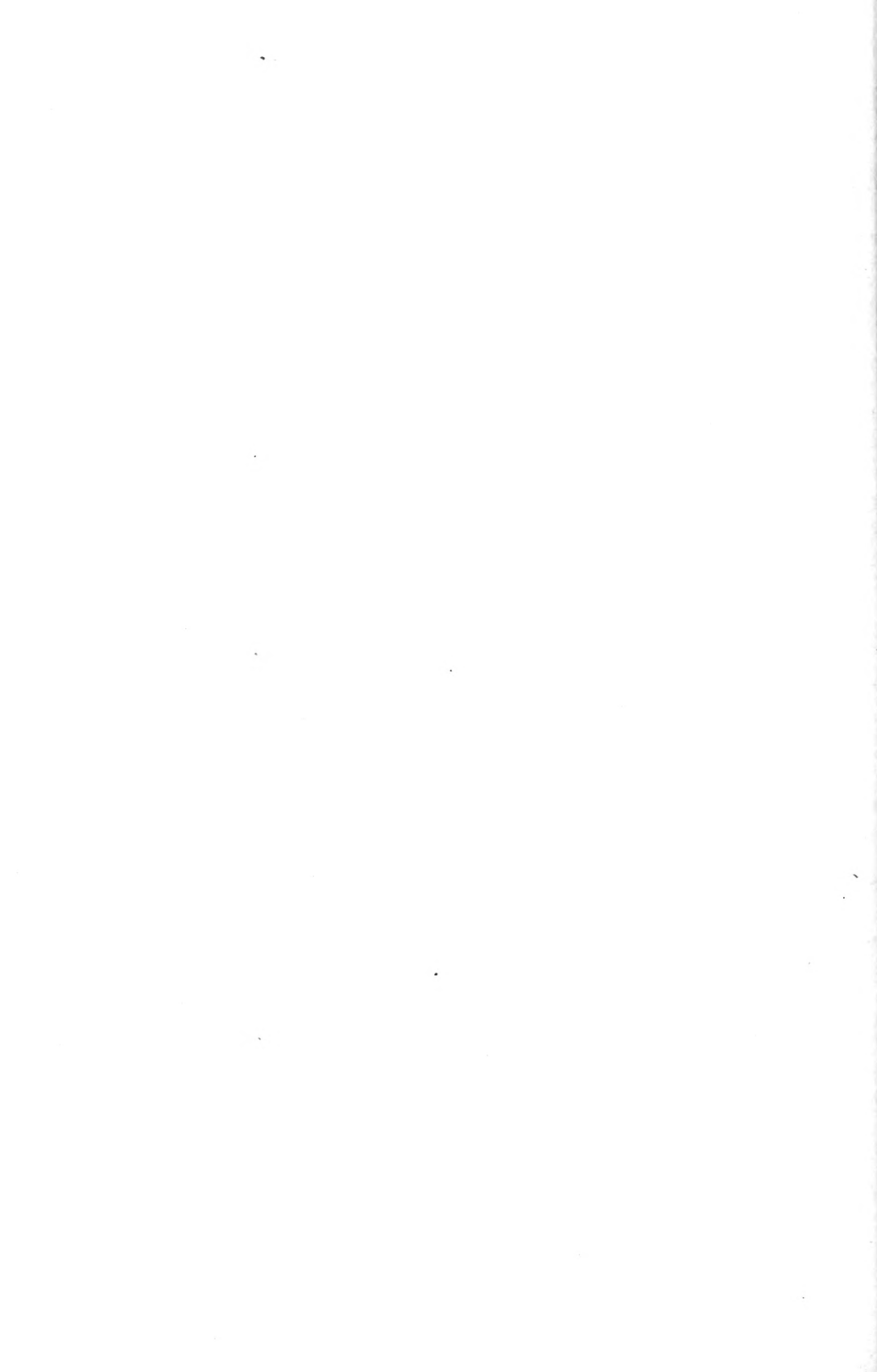
Orientation:  $a = a$ ,  $b = c$ .

Colorless, yellow, yellowish brown, reddish.

Pleochroism: Weak in yellow and colorless tones.

$\beta = 1.643$ .

$\gamma - \alpha = 0.035$ .





Dispersion: Weak,  $\rho > \nu$ .

$2V = 68^\circ$ .

Gelatinizes quite easily with HCl.

Occurs as a not especially common constituent of crystalline dolomites and limestones.

**Olivine** resembles colorless humite, but has the plane of the optic axes at right angles to the cleavage, while in humite this is parallel to the cleavage.

**Olivine.**—(Mg,Fe)SiO<sub>4</sub>, H=6.5–7.0, G=3.27–3.45.

Orthorhombic. (+).

Cleavage: (010), (001), distinct; (100), poor. Generally shows heavy irregular cracks.

Habit: Isometric, short prisms, grains. Twins (011) and (012) rare.

Orientation:  $a = c$ ,  $b = a$ .

Greenish, yellowish, reddish, colorless.

Pleochroism: Wanting or weak in yellow and red tones.

$\alpha = 1.654$ ,  $\beta = 1.670$ ,  $\gamma = 1.689$ .

$\gamma - \alpha = 0.035$ ,  $\gamma - \beta = 0.019$ ,  $\beta - \alpha = 0.016$ .

Dispersion: Distinct,  $\rho < \nu$ .

$2V = 88^\circ$  ca.

Gelatinizes slowly in HCl.

**Diopside** has two equally good cleavages to which the extinction is inclined; olivine has two very unequal cleavages to which the extinction is parallel in the principal zone. Diopside does not gelatinize with HCl.

**Fayalite** has  $2V = 50^\circ$ , higher birefringence, and is (–).

**Forsterite** has lower indices, and occurs as a contact mineral in metamorphosed limestones.

**Monticellite** is (–), and has  $2V = 37.5^\circ$ .

**Augite** and **diallage** when in sections showing parallel extinction have different orientation of interference figures.

**Monazite.**—(Ce,La,Di)PO<sub>4</sub>, H=5.5, G=4.9–5.3.

Monocline. (+).

Cleavage: (100), (010), distinct.

Habit: Tablets, often elongated on  $b$ .

Elongation: (001):(100), short laths. (–).

Orientation:  $b = a$ ,  $c : a = 2^\circ$  to  $6^\circ$ .

Colorless, yellowish.

Non-pleochroic in thin sections.

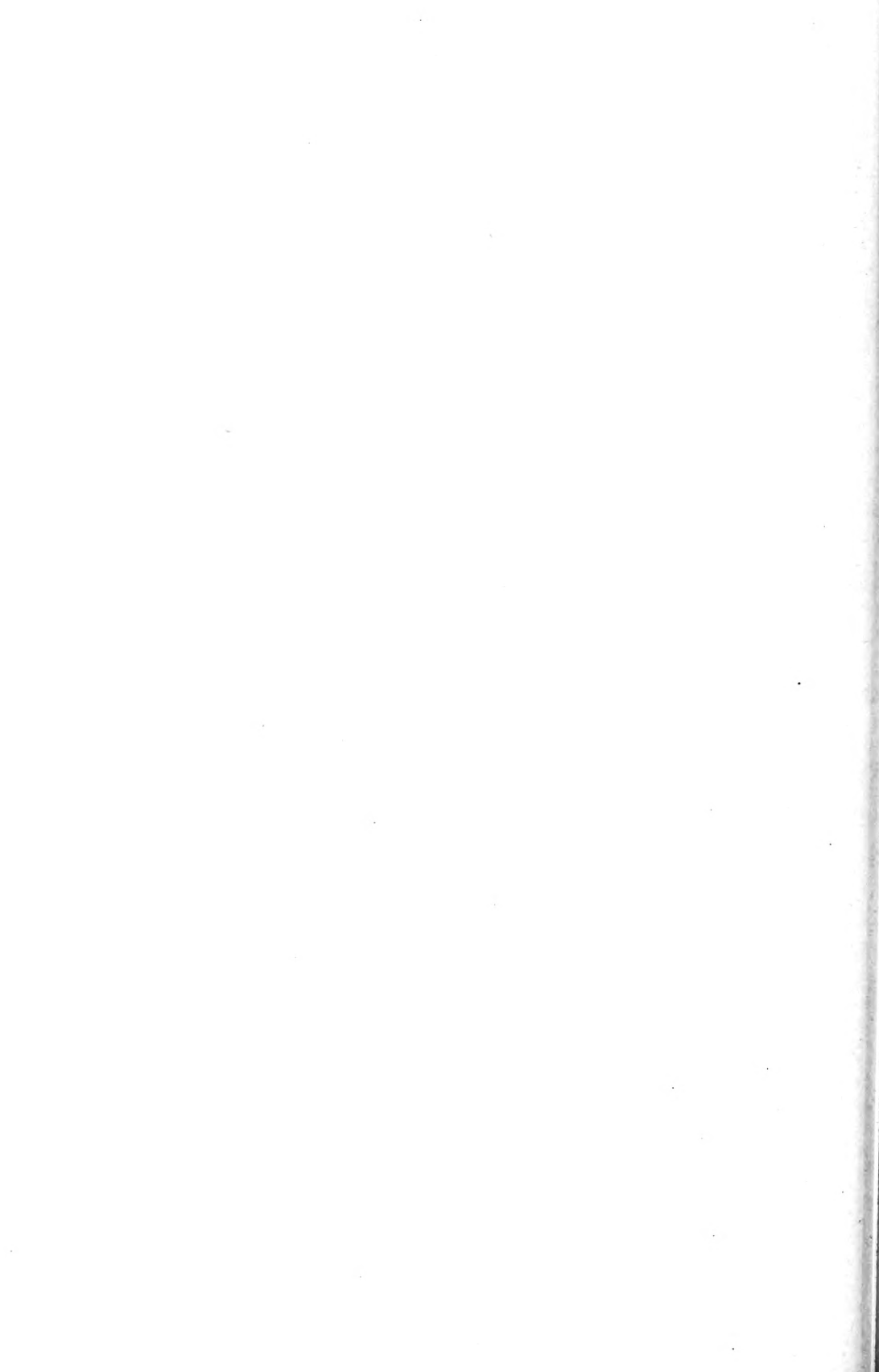
$\alpha = 1.796$ ,  $\beta = 1.797$ ,  $\gamma = 1.841$ .

$\gamma - \alpha = 0.045$ ,  $\gamma - \beta = 0.044$ ,  $\beta - \alpha = 0.001$ .

Dispersion: Weak,  $\rho < \nu$ .

$2E = 21^\circ$ – $36^\circ$ .

Cut on line.



Soluble with difficulty in HCl, leaving a white residue.

**Olivine** has  $2V=88^\circ$  ea., and contains no P.

**Titanite** has strong dispersion,  $\rho > \nu$ , contains no P., extinction  $+39^\circ$ , weak pleochroism, and much higher birefringence.

**Brookite.**— $\text{TiO}_2$ ,  $H=5.5-6.0$ ,  $G=3.87-4.01$ .

Orthorhombic. (+).

Cleavage: (010), good, though not always seen microscopically.

Habit: Tabular, plates.

Elongation: (100), narrow laths. ( $\mp$ ).

Orientation:  $a=c$ ,  $b=a$ , for red;  $a=c$ ,  $c=a$ , for green. Axial plane for red and yellow lies in (001); for green and blue in (010).

$\alpha=2.583$ ,  $\beta=2.586$ ,  $\gamma=2.741$ .

$\gamma-\alpha=0.158$ ,  $\gamma-\beta=0.156$ ,  $\beta-\alpha=0.003$ .

Dispersion:  $\rho > \nu$ .

$2V=0^\circ-23^\circ$ .

Insoluble in acids. Gives Ti reaction.

**Cassiterite** and **rutile** have different habit, and brookite has very different strength of double refraction in (100) and (010) sections.

**Pseudobrookite.**— $\text{TiO}_2$  and  $\text{Fe}_2\text{O}_3$ ,  $H=6.0$ ,  $G=4.39-4.93$ .

Orthorhombic. (+).

Cleavage: (010), distinct.

Habit: Plates, always idiomorphic.

Elongation: (100), narrow laths. ( $\pm$ )

Orientation:  $a=c$ ,  $b=a$ .

Fox-red, brownish.

Pleochroism: Weak,  $b > a=c$

$\beta$ =high.

$\gamma-\alpha$ =high.

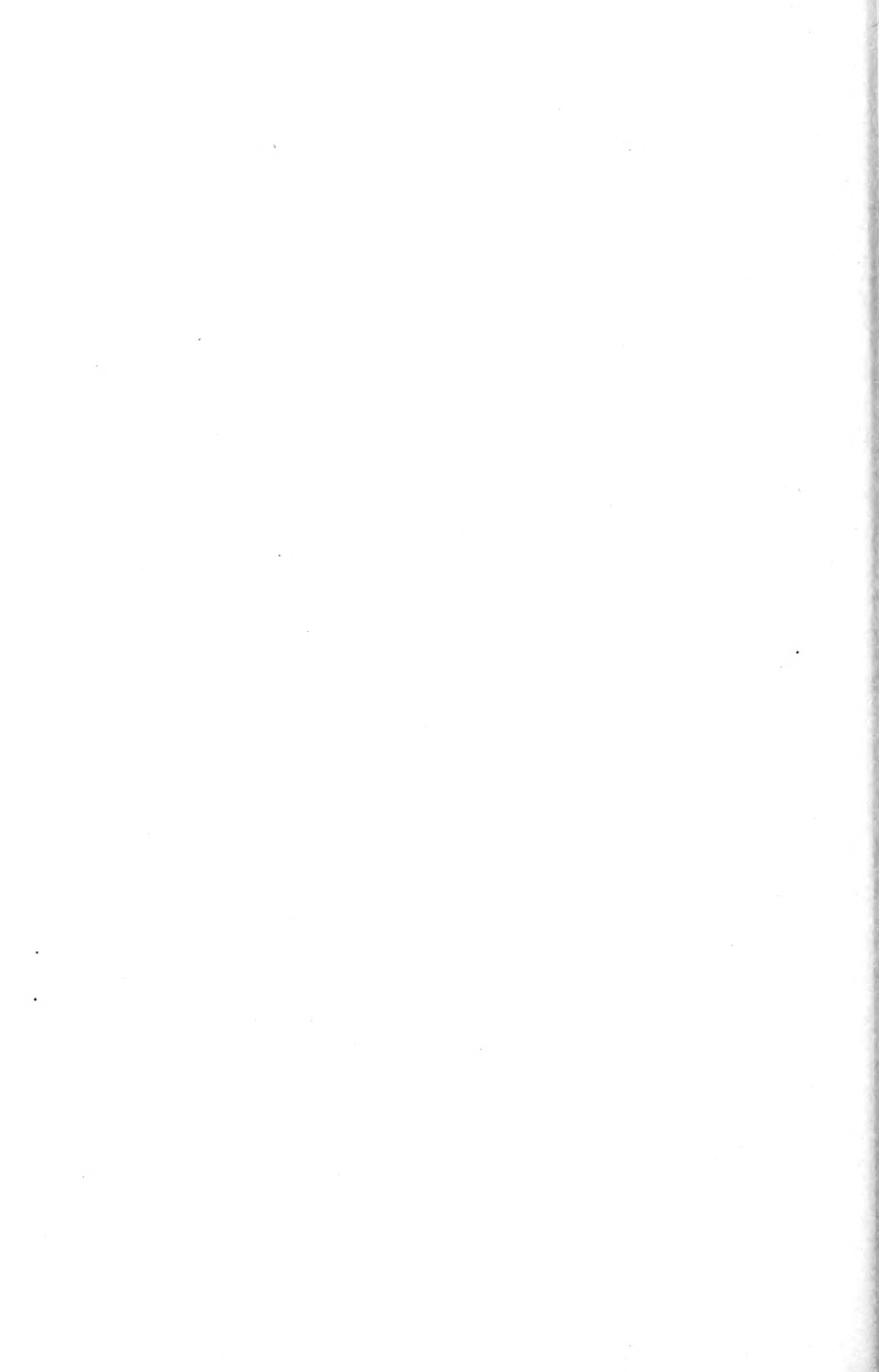
Dispersion:  $\rho < \nu$ .

$2H=84.5^\circ$ .

Partially decomposed by boiling HCl.

**Brookite** in tablets has low double refraction;  $\beta-\alpha=0.003$ ,  $2V$  is smaller, and  $\rho > \nu$ .

*Cut on line.*



The mineral is **anisotropic**.

**Parallel extinction.**

**Colored.**

**Pleochroic.**

**PLEOCHROIC.**

*Cut on line.*



The mineral is **anisotropic**.

**Parallel extinction.**

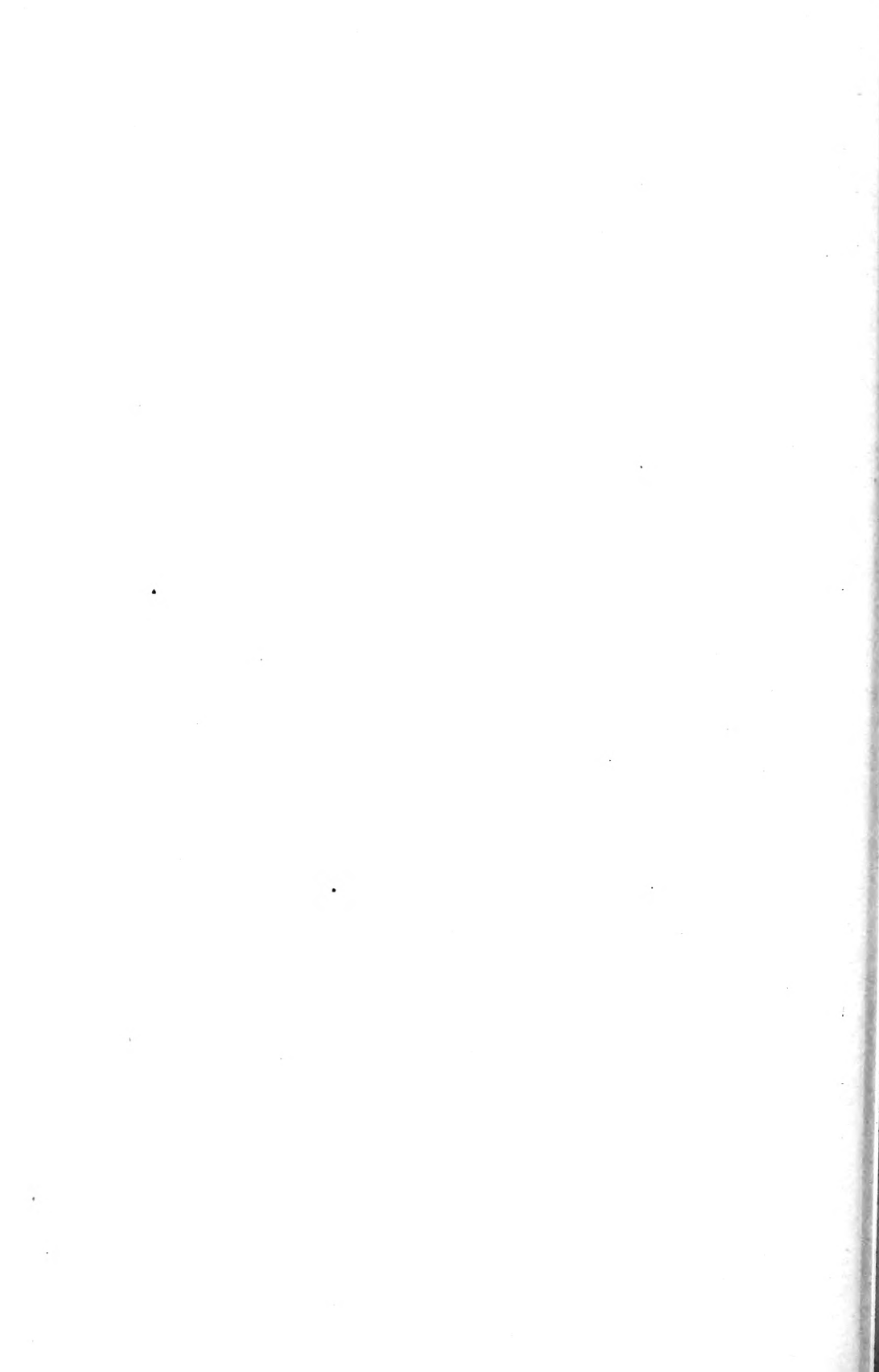
**Colored.**

**Pleochroic.**

**Maximum birefringence is less**  
than that of quartz.

BIREFRINGENCE < QUARTZ.

*Cut on line.*





The mineral is anisotropic.

Parallel extinction.

Colored.

Pleochroic.

Maximum birefringence is less  
than that of quartz.

Uniaxial.

UNIAXIAL.

*Cut on line.*

The Mineral is ANISOTROPIC, has PARALLEL EXTINCTION, is COLORED, PLEOCHROIC, MAXIMUM BIREFRINGENCE < Quartz, UNIAXIAL.											
The Mineral is NEGATIVE (-).						The Mineral is POSITIVE (+).					
← Increase in Index of Refraction. →											
1.50 1.55 1.60 1.65 1.70	1.70	1.65	1.60	1.55	In- creasing BIREFR.	1.55	1.60	1.65	1.70	1.75 1.80 1.85 1.90 1.95	1.50 1.55 1.60 1.65 1.70
Very H.	High.	Medium.	Not Marked.			Not Marked.	Medium.		High.		Very H.
					.001						
					.002						
					.003						
		Apatite.*			.004						
		Melilite.			.005						
Vesuvianite					.006						
					.007						
					.008						
	Corundum.				.009						
					.010						

**Apatite.**—  $\text{CaF} \cdot \text{Ca}_4(\text{PO}_4)_3$  and  $\text{CaCl} \cdot \text{Ca}_4(\text{PO}_4)_3$ ,  $H = 5.0$ ,  $G = 3.10-3.22$ .  
Hexagonal. (—).

Cleavage: (0001), (10 $\bar{1}$ 0), poor; long prisms often show cross-fractures.

Habit: Long prisms, rounded grains, granular aggregates.

Elongation: (10 $\bar{1}$ 0):(01 $\bar{1}$ 0), lath-shaped. (—).

Colorless, violet, brownish, reddish, gray.

Absorption:  $E > O$ , in colored crystals.

$\omega = 1.638$ ,  $\varepsilon = 1.634$ .

$\omega - \varepsilon = 0.004$ .

Anomalous biaxial character in large individuals only.

Easily soluble in  $\text{H}_2\text{SO}_4$ , yellow precipitate with ammonium molybdate. Easily soluble in  $\text{HNO}_3$ .

**Vesuvianite, melilite, gehlenite, zoisite, and tourmaline** are not soluble or have different crystal form or color.

**Tourmaline** has  $O > E$ , while colored apatite has  $E > O$ .

**Melilite.**—  $\text{Ca}, \text{Mg}, \text{Fe}, \text{Al}$ , silicate,  $H = 5.0$ ,  $G = 2.9-3.1$ .  
Tetragonal. (±).

Cleavage: (001):(110), poor; only basal cleavage generally seen in thin sections, and this occurs as a single cleft exactly in the center of the lath-shaped section.

Habit: Plates, short prisms.

Elongation: (001), laths. (±).

Colorless, yellowish.

Pleochroism: None when colorless; for yellow melilite  $E = \text{dark yellow}$ ,  $O = \text{light yellow}$ .

$\omega = 1.634$ ,  $\varepsilon = 1.629$ .

$\omega - \varepsilon = 0.005$ ; often unusual indigo-blue interference colors.

Gelatinizes easily with  $\text{HCl}$ . "Peg" structure and cleavage crack in center are characteristic.

**Vesuvianite and zoisite** are insoluble in acids.

**Gehlenite** has not the unusual interference colors.

**Vesuvianite.**—  $\text{Al}_2(\text{SiO}_4)_2\text{Ca}_6(\text{AlOH})$ ,  $H = 6.5$ ,  $G = 3.35-3.47$ .  
Tetragonal. (—, rarely +).

Cleavage: (110), (100), poor.

Habit: Short prisms, grains, dull masses.

Elongation: (110):(1 $\bar{1}$ 0), prismatic. (±).

Colorless, yellowish, greenish, reddish, brownish, blue.

Pleochroism: Weak to unnoticeable.

$\omega = 1.705-1.732$ ,  $\varepsilon = 1.701-1.726$ .

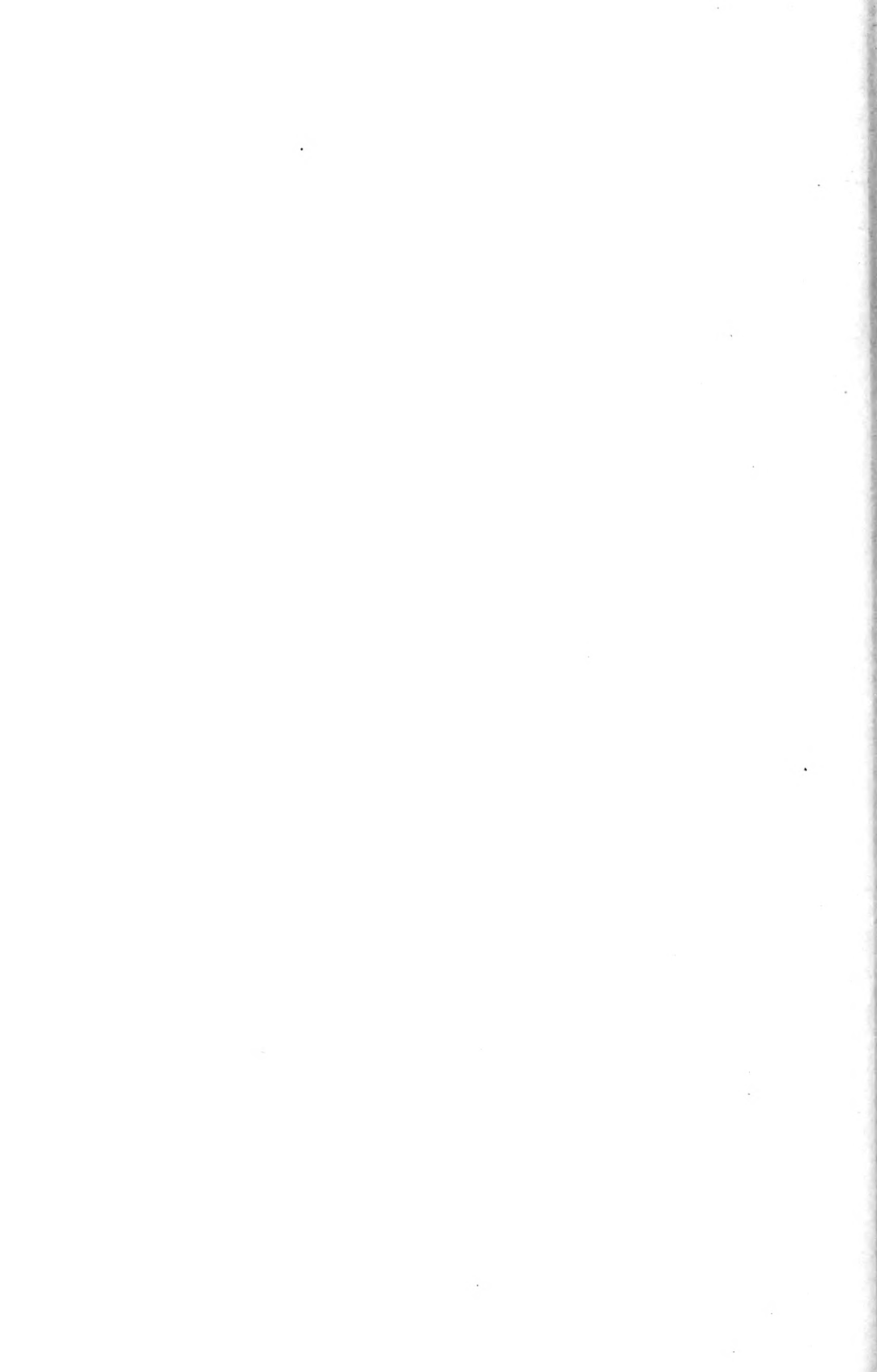
$\omega - \varepsilon = 0.006-0.001$ , often abnormal interference colors.

Anomalous biaxial character.

Insoluble in acids unless fused to glass.

**Zoisite** has the high indices and weak double refraction found in vesuvianite. The optic angle of zoisite often

Cut on line.



falls as low as  $0^\circ$ , and vesuvianite has often anomalous double refraction with very variable axial angle. Zoisite, however, has very good pinacoidal cleavage.

Gehlenite gelatinizes easily with HCl.

Andalusite always has a larger axial angle.

**Corundum.**— $\text{Al}_2\text{O}_3$ ,  $H=9.0$ ,  $G=3.9-4.10$ .

Hexagonal. (—).

Cleavage: There is a parting along  $(10\bar{1}1)$ .

Habit: Plates, grains, prisms. Twinning lamellae  $(10^{11})$  occur, and parting is along these planes.

Elongation:  $(0001)$ , lath-shaped. (+).

Colorless, blue, light red.

Pleochroism:  $O$  = blue, red;  $E$  = green, yellow, or greenish yellow. Only seen in deeply colored corundum.

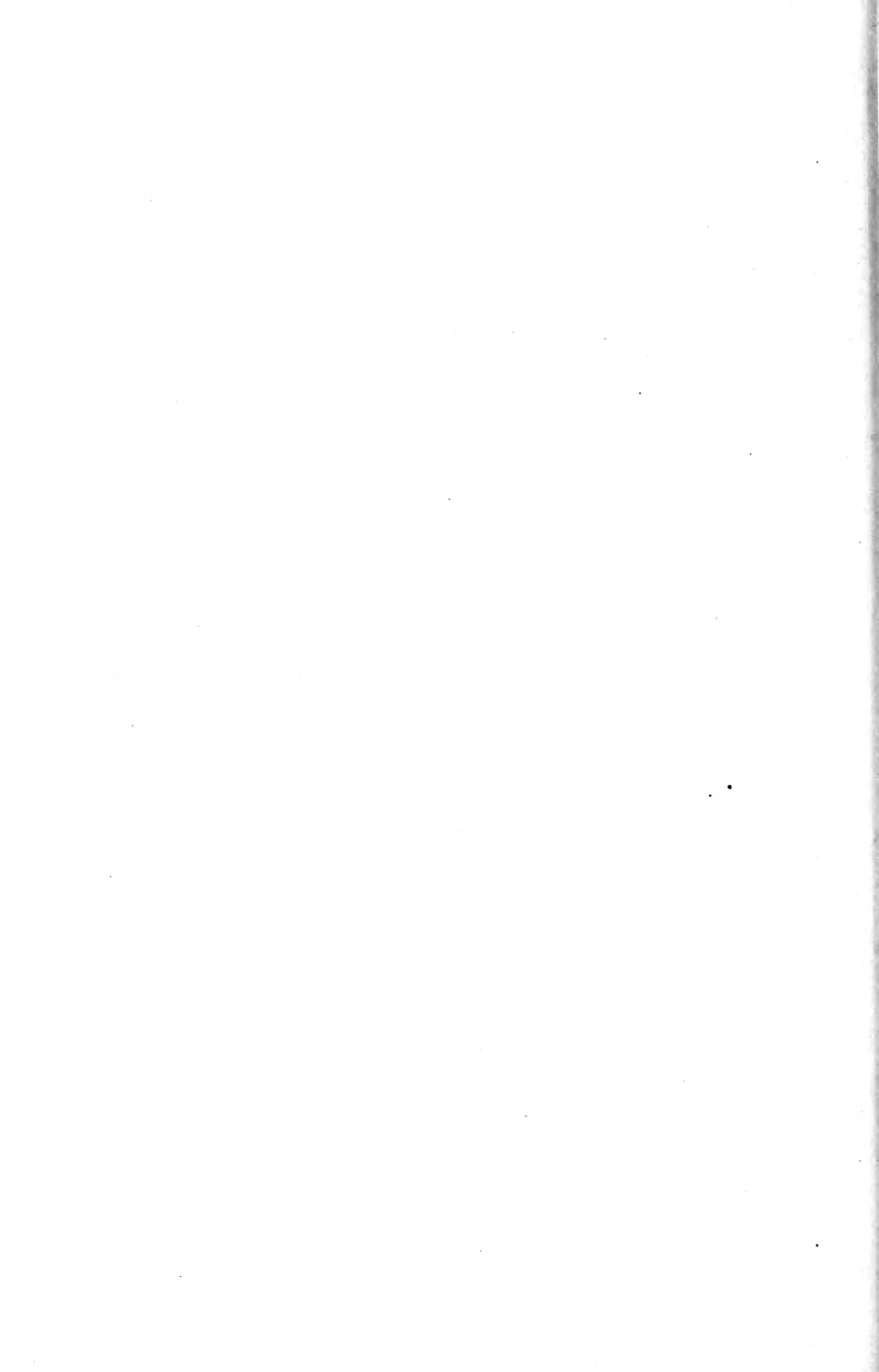
$\omega=1.769$ ,  $\epsilon=1.760$ .

$\omega-\epsilon=0.009$ .

Insoluble in acids or fused soda.

**Other minerals** which resemble it are separated by the high indices, negative character, uniaxial figure, etc., of corundum.

*Cut on line.*



The mineral is **anisotropic**.

**Parallel extinction.**

**Colored.**

**Pleochroic.**

**Maximum birefringence is less**  
than that of quartz.

**Biaxial.**

**BIAXIAL.**

*Cut on line.*

The Mineral is ANISOTROPIC, has PARALLEL EXTINCTION, is COLORED, PLEOCHROIC. MAXIMUM BIREFRINGENCE < Quartz, BIAxIAL.											
The Mineral is NEGATIVE (-).						The Mineral is POSITIVE (+).					
← Increase in Index of Refraction →											
1.50 NN-1.00 1.80 1.75	1.70	1.65	1.60	1.55	In- crease BIREFR.	1.55	1.60	1.65	1.70	1.75 1.80 1.90 2.00 2.50	Very H.
Very H.	High.	Medium.	Not Marked.			Not Marked.	Medium.		High.		Very H.
					001						
			Thuringite. = Pennine. ±		002		- Pennine. ±				
					003						
					004						
Sapphirine. =					005						
					006						
					007						
					008						
			Cordierite. =		009		Enstatite. =	Bronzite.		Thulite.	
					010						



Thuringite.— $\text{H}_{18}\text{Fe}_8(\text{AlFe})_8\text{Si}_6\text{O}_{41}$ ,  $\text{H} = 2.5$ ,  $\text{G} = 3.15\text{--}3.19$ .

Monoclinic. (—).

Cleavage: (001), good.

Habit: Scales, irregular or concentric scaly aggregates.

Elongation: At right angles to (001), lath-shaped. (+).

Orientation:  $c: a = 0^\circ$ .

Green, yellow.

Pleochroism:  $a$  = yellow;  $b = c$  = green.

Index similar to pennine, 1.583.

Birefringence similar to pennine, 0.002.

$2E = 0^\circ\text{--}25^\circ$  ea.

A lepto-chlorite.

Gelatinizes easily with HCl.

Sapphirine.— $\text{Mg}_5\text{Al}_{12}\text{Si}_2\text{O}_{27}$ ,  $\text{H} = 7.5$ ,  $\text{G} = 3.486$ .

Monoclinic. (—).

Cleavage: Not seen.

Habit: Tablets, rods, grains.

Elongation: (110):(110), lath-shaped. (+).

Orientation:  $b = b$ ,  $c: r = +8^\circ$  to  $+9^\circ$ .

Bluish, greenish, colorless.

Pleochroism:  $a$  = colorless;  $b = c$  = blue; or  $a$  = light greenish blue;

$b$  = dark blue-green;  $c = r$  = yellowish green.

$\alpha = 1.706$ ,  $\beta = 1.709$ ,  $\gamma = 1.711$ .

$\gamma - \alpha = 0.005$ ,  $\gamma - \beta = 0.002$ ,  $\beta - \alpha = 0.003$

Dispersion: Distinct,  $\rho < \nu$ .

$2V = 69^\circ$ .

Insoluble in acids.

Corundum is uniaxial and has parallel extinction.

Lazulite has higher double refraction.  $\gamma - \alpha = 0.036$ .

Cyanite, brittle micas, and blue amphibole show cleavage lines.

Blue cordierite has lower indices of refraction.  $\alpha = 1.535$ .

Serendibite has polysynthetic twinning.

Cordierite.— $\text{Mg}_2\text{Al}_4\text{Si}_5\text{O}_{18}$ ,  $\text{H} = 7.0\text{--}7.5$ ,  $\text{G} = 2.59\text{--}2.66$ .

Orthorhombic. (—).

Cleavage: (010), poor.

Habit: Grains, short prisms. Trillings and polysynthetic twins occur.

Elongation: (110):(110), short laths. (—).

Orientation:  $b = r$ ,  $r = a$ .

Colorless, bluish, yellowish.

Pleochroism: Wanting or weak with  $b > r > a$ .

$\alpha = 1.535$ ,  $\beta = 1.540$ ,  $\gamma = 1.544$ .

$\gamma - \alpha = 0.009$ ,  $\gamma - \beta = 0.004$ ,  $\beta - \alpha = 0.005$ .

Dispersion: Weak,  $\rho < \nu$ .

$2E = 63^\circ$  to  $150^\circ$ .

When treated with HF gives characteristic prismatic crystals of magnesium fluosilicate.

Quartz has higher interference colors, is uniaxial, and (+). Chemically different, reactions as above.



**Pennine.**—A magnesium aluminium silicate,  $H=2.0-2.5$ ,  $G=2.73$ .

Monoclinic. ( $\pm$ ).

Cleavage: (001), good.

Habit: Leaves, scales, leafy aggregates.

Elongation: At right angles to (001), lath-shaped. ( $\pm$ ).

Orientation:  $b=b$ ,  $c:c$  or  $a=0^\circ$ .

Green.

Pleochroism:  $b$  and  $a$ =green;  $c$ =yellowish.

$\alpha=1.582$ ,  $\beta=(\quad)$ ,  $\gamma=1.584$ .

$\gamma-\alpha=0.002$ .

Dispersion:  $\rho > \nu$ , or  $\rho < \nu$ .

$2E=0^\circ$  to  $61^\circ$ .

Partially decomposed by HCl.

Often abnormal interference colors.

**Micas** have higher double refraction and different pleochroism.

**Brittle micas** have different pleochroism.

**Other minerals** do not have the scale-like character.

**Serpentine** has higher birefringence and lower indices. The separation from antigorite may be difficult and is sometimes only possible chemically. Serpentine is usually much less pleochroic.

See also Chlorite group. Part II, p. 53.

**Enstatite.**— $(Mg, Fe)_2SiO_6$ ,  $H=5.0-6.0$ ,  $G=3.1$ .

Orthorhombic. (+).

Cleavage: (110), good; (010), distinct; (100), good. (110):(110) =  $91^\circ 40'$ .

Habit: Prismatic, cloudy masses.

Elongation: (110):(110), lath-shaped. (+).

Orientation:  $b=a$ ,  $c=c$ .

Colorless.

Pleochroism: Wanting.

$\alpha=1.656$ ,  $\beta=1.659$ ,  $\gamma=1.665$ .

$\gamma-\alpha=0.009$ ,  $\gamma-\beta=0.006$ ,  $\beta-\alpha=0.003$ .

Dispersion:  $\rho < \nu$ .

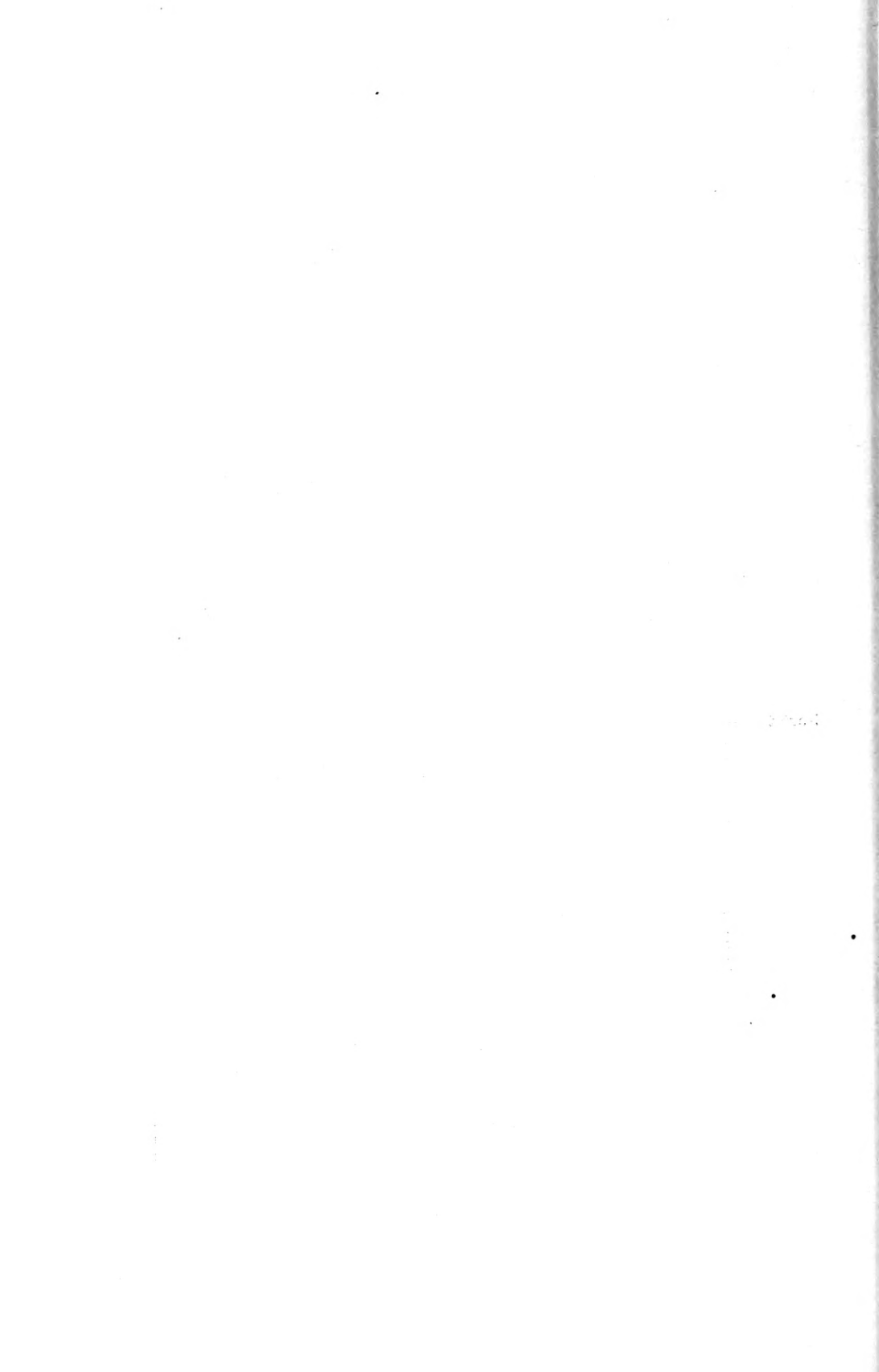
$2E=135^\circ$  ca.

Insoluble in acids.

**Monoclinic pyroxenes** have higher double refraction and inclined extinction. In basal sections the monoclinic pyroxenes show the emergence of an axis, while the orthorhombic pyroxenes show the emergence of a positive bisectrix.

**Ægirite** is pleochroic, has higher double refraction, and (−) elongation.

Cut on line.



**Bastite** cleavage flakes along the best pinacoidal cleavage show the emergence of a negative bisectrix with small axial angle; enstatite shows the emergence of the optic normal.

**Diallage**, in similar flakes, shows the emergence of an optic axis.

**Bronzite**.— $(\text{Mg,Fe})_2\text{Si}_2\text{O}_6$ ,  $H = 5.0-6.0$ ,  $G = 3.29$ .

Orthorhombic. (+).

Cleavage: (010), distinct; (100), good; (110) good.  $(110):(110) = 91^\circ 40'$ .

Habit: Prismatic, cloudy masses. Geniculated and star-shaped twins occur rarely.

Elongation:  $(110):(1\bar{1}0)$ , lath-shaped. (+).

Orientation:  $b = a$ ,  $c = c$ .

Colorless, yellowish, reddish.

Pleochroism: Weak;  $c$  = greenish,  $a$  = reddish yellow,  $b$  = reddish brown.

$\alpha = 1.665$ ,  $\beta = 1.663$ ,  $\gamma = 1.674$ .

$\gamma - \alpha = 0.009$ ,  $\gamma - \beta = 0.005$ ,  $\beta - \alpha = 0.004$ .

Dispersion:  $\rho < \nu$ .

$2E = 106^\circ$  ca.

An orthorhombic pyroxene.

**Hypersthene** has the same pleochroism, strong, and is (-).

**Monoclinic pyroxenes**, see enstatite above, also Part II.

**Thulite**.—Manganese zoisite,  $H = 6.0-6.5$ ,  $G = 3.124$ .

Orthorhombic. (+).

Cleavage: (100), distinct.

Habit: Rods, leaves.

Elongation:  $(110):(1\bar{1}0)$ , lath-shaped. ( $\pm$ ).

Orientation:  $a = c$ ,  $c = a$ .

Red, yellow.

Pleochroism:  $a$  = nearly colorless,  $b$  = rose,  $c$  = yellowish.

Index:  $n = 1.702$ .

Birefringence: Like zoisite = 0.009 maximum.

Dispersion:  $\rho < \nu$ .

$2V = 0-40^\circ$ .

Insoluble in acids.

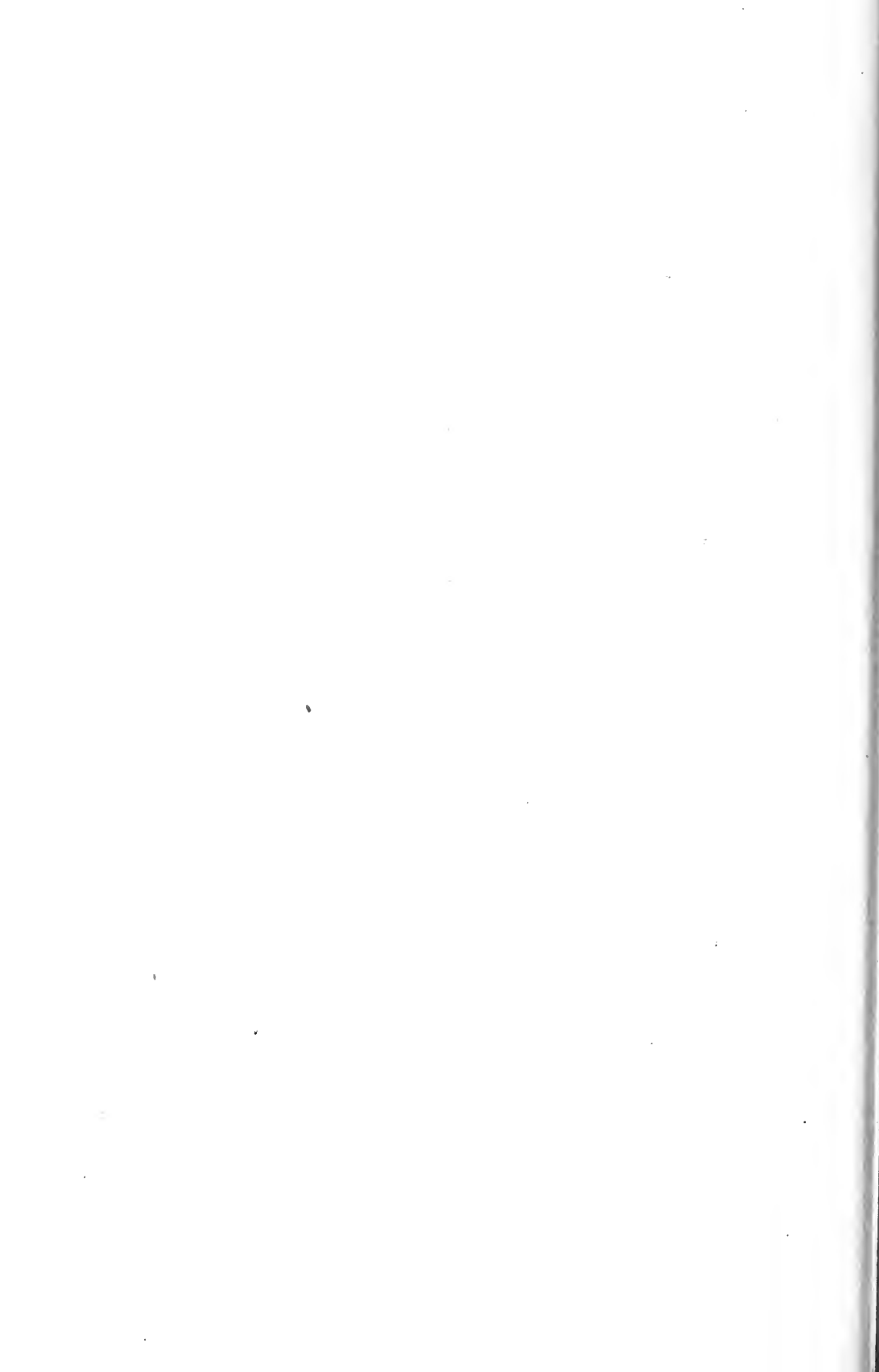
Abnormal interference colors.

**Zoisite** is non-pleochroic.

**Epidote** with weak double refraction is similar when the axial plane is at right angles to the cleavage. Pleochroism is different.

**Vesuvianite** has poor cleavage.

**Melilite** gelatinizes with acids.



The mineral is **anisotropic**.

**Parallel** extinction.

**Colored**.

**Pleochroic**.

**Maximum birefringence** is greater  
than that of quartz.

BIREFRINGENCE > QUARTZ.

*Cut on line.*





The mineral is **anisotropic**.

**Parallel** extinction.

**Colored**.

**Pleochroic**.

**Maximum birefringence** is greater  
than that of quartz.

**Uniaxial**.

UNIAXIAL.

*Cut on line.*



**Corundum.**— $\text{Al}_2\text{O}_3$ ,  $H=9.0$ ,  $G=3.9-4.10$ .

Hexagonal. (—).

Cleavage: There is a parting along  $(10\bar{1}1)$ .

Habit: Plates, grains, prisms. Twinning lamellæ  $(10\bar{1}1)$  occur and parting is along these planes.

Elongation:  $(0001)$ , lath-shaped. (+).

Colorless, blue, light red.

Pleochroism:  $O$ =blue, red;  $E$ =green, yellow or greenish yellow; only seen in deeply colored corundum.

$\omega=1.769$ ,  $\epsilon=1.760$ .

$\omega-\epsilon=0.009$ .

Insoluble in acids or fused soda.

Other minerals which resemble it are distinguished by the high indices, negative character, uniaxial figure, etc., of corundum.

**Tourmaline.**— $\text{Na,Al,B,Mg,Fe}$  silicate,  $H=7.0$ ,  $G=3.0-3.24$ .

Hexagonal. (—).

Cleavage: Not seen in thin sections.

Habit: Prisms, grains, rod-like aggregates.

Elongation:  $(10\bar{1}0)$ , prismatic. (—).

Orientation:  $c=a$ .

Brown, reddish, greenish, yellow, violet, blue.

Pleochroism: Strong,  $O>E$ .

$\omega=1.632-1.685$ ,  $\epsilon=1.612-1.652$ .

$\omega-\epsilon=0.017-0.034$ .

Often anomalous biaxial character.

Insoluble in HF and other acids.

Other minerals: The strong pleochroism,  $O>E$ , the form, lack of cleavage, and insolubility in acids separate tourmaline from all other minerals.

**Biotite.**— $\text{Mg,Fe,Al}$  silicate,  $H=2.5-3.0$ ,  $G=2.8-3.2$ .

Monoclinic, often appears uniaxial. (—).

Cleavage:  $(001)$ , good.

Habit: Leaves, leafy aggregates.

Elongation: At right angles to  $(001)$ , lath-shaped. (+).

Orientation:  $b=b$ ,  $c:a=0^\circ$  to  $+7^\circ$ .

Brown, green, yellow.

Pleochroism: Strong,  $\epsilon \geq b > a$ ;  $\epsilon$  and  $b$ =deep brown to red-brown, deep green to black;  $a$ =light yellow to red, light green.

$\alpha=1.557$ ,  $\beta=1.589$ ,  $\gamma=1.597$ .

$\gamma-\alpha=0.040$ ,  $\gamma-\beta=0.008$ ,  $\beta-\alpha=0.032$ .

Dispersion: Weak,  $\rho \geq \nu$ .

$2E=0^\circ$  to  $72^\circ$ .

Soluble in  $\text{H}_2\text{SO}_4$  and the Fe-rich biotites in HCl with separation of  $\text{SiO}_2$  scales.

Cut on line.



**Minerals other than micas**, see Part II.

**Alkali micas** have different color, pleochroism, larger  $2V$ , different position of the plane of the optic axes, and are different chemically.

**Anomite** has different position of the plane of the optic axes.

**Lithionite**, when dark in color, may be distinguished by the Li reaction.

**Anatase.**— $\text{TiO}_2$ ,  $H = 5.5-6.0$ ,  $G = 3.82-3.95$ .

Tetragonal. (—).

Cleavage: (001), (111), good.  $(111):(1\bar{1}\bar{1}) = 43^\circ 24'$ .

Habit: Pyramids, tabular.

Colorless, blue, also yellowish or greenish.

Pleochroism:  $O$  = deep blue, orange yellow;  $E$  = light blue, light yellow.

$\omega = 2.562$ ,  $\epsilon = 2.489$ .

$\omega - \epsilon = 0.0732$ .

Optical anomalies, interference cross opens; colorless and yellow anatase is usually normal, blue portion seldom fully extinguishes.

**Rutile**, **brookite**, **pseudobrookite**, **cassiterite**, and **zircon** differ in being (+) and by having different cleavage and form.

**Perofskite** has different form, and the anomalous interference colors are lower than those in anatase.

**Calcite.**— $\text{CaCO}_3$ ,  $H = 3.0$ ,  $G = 2.714$ .

Hexagonal. (—).

Cleavage: (10 $\bar{1}$ 1), good.  $(10\bar{1}1):(1\bar{1}01) = 74^\circ 55'$ .

Habit: Grains, granular aggregates, threads, rounded aggregates.

Colorless, gray, yellowish, brownish.

Absorption:  $O > E$ .

$\omega = 1.658$ ,  $\epsilon = 1.486$ .

$\omega - \epsilon = 0.172$ .

Twinning (01 $\bar{1}$ 2) common.

Often incloses rhombs of dolomite and magnesite. Readily soluble in cold HCl.

**Aragonite** is biaxial and has different cleavage. See also special tests in Part II.

**Dolomite** has (02 $\bar{2}$ 1) twinning. Special tests, see Part II.

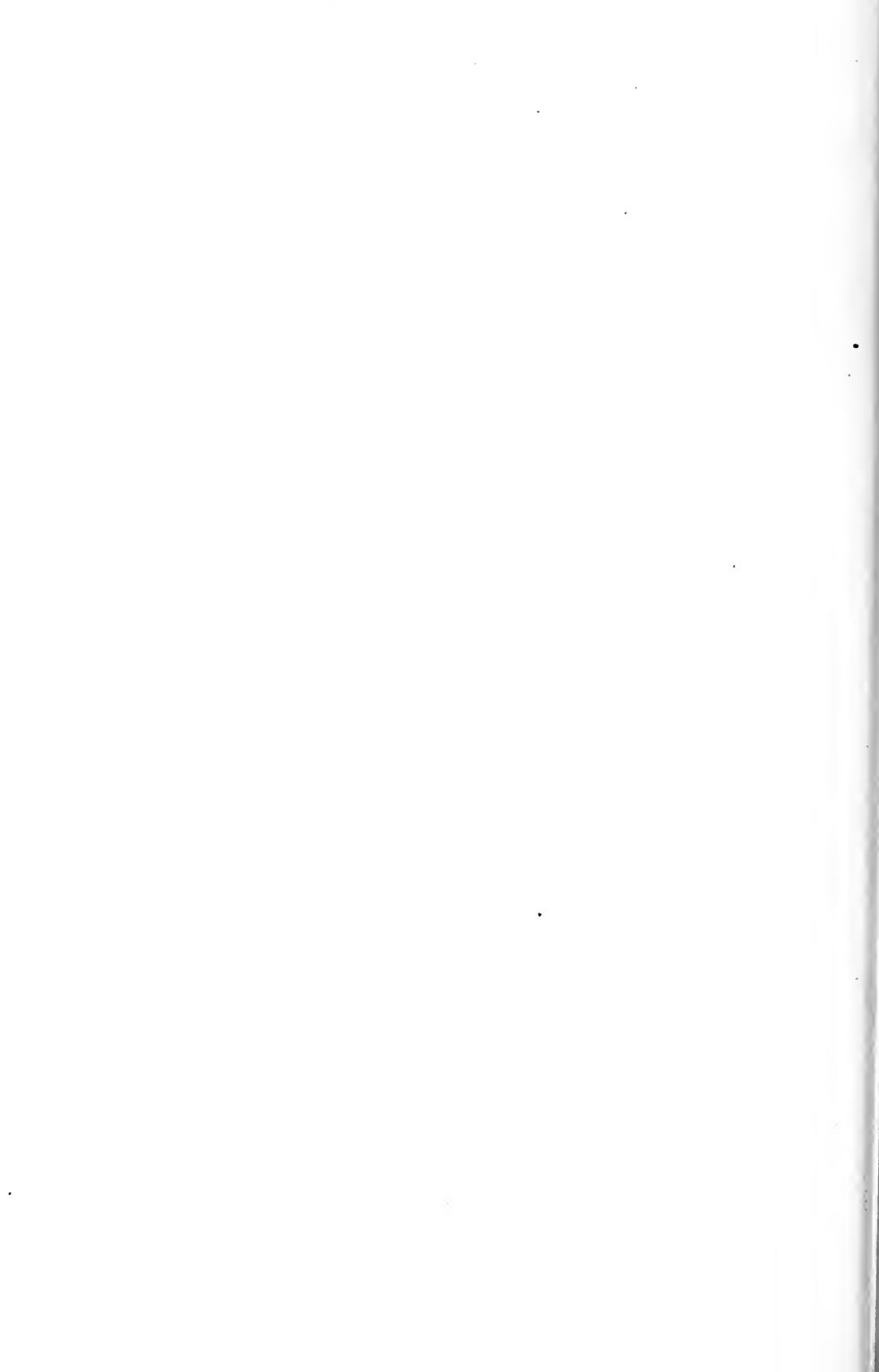
**Dolomite.**— $\text{MgCaC}_2\text{O}_6$ ,  $H = 3.5-4.0$ ,  $G = 2.85-2.95$ .

Hexagonal. (—).

Cleavage: (10 $\bar{1}$ 1), good.

Habit: Rhombohedrons, granular aggregates. Twins (02 $\bar{2}$ 1) occasionally occur.

*Cut on line.*



Colorless, gray, yellowish, brownish.

Absorption:  $O > E$ , strong.

$\omega = 1.682$ ,  $\varepsilon = 1.503$ .

$\omega - \varepsilon = 0.179$ .

Soluble with difficulty in cold acid; easily in hot.

**Calcite** has lower indices and is soluble in acetic acid, twinning (01 $\bar{1}$ 2). Chemical differences between calcite, dolomite, and aragonite, see Part II.

**Magnesite.**— $\text{MgCO}_3$ ,  $H = 3.5-4.5$ ,  $G = 2.9-3.1$ .

Hexagonal. (—).

Cleavage: (10 $\bar{1}$ 1), good. (10 $\bar{1}$ 1):(1101) =  $72^\circ 40'$ .

Habit: Rhombohedrons, granular aggregates.

Colorless, yellowish, grayish, brownish.

Absorption:  $O > E$ .

$\omega_{na} = 1.717$ ,  $\varepsilon_{na} = 1.515$ .

$\omega - \varepsilon = 0.202$ .

Cold HCl does not act upon magnesite.

**Dolomite** and **calcite** are acted upon more readily by acids.

See also special tests in Part II.

**Siderite.**— $\text{FeCO}_3$ ,  $H = 3.5-4.0$ ,  $G = 3.936-3.938$ .

Hexagonal. (—).

Cleavage: (10 $\bar{1}$ 1), good. (10 $\bar{1}$ 1):(1101) =  $73^\circ$ .

Habit: Rhombohedrons, granular aggregates.

Colorless, yellowish, brownish.

Absorption: Strong,  $O > E$ .

$\omega = 1.872$ ,  $\varepsilon = 1.634$ .

$\omega - \varepsilon = 0.238$ .

Soluble in HCl.

**Other carbonates** are separated by chemical means.

**Hematite.**— $\text{Fe}_2\text{O}_3$ ,  $H = 5.5-6.5$ ,  $G = 4.9-5.3$ .

Hexagonal. (—).

Cleavage: Parting, (0001) and (10 $\bar{1}$ 1).

Habit: Tabular, thin plates, scales, earthy masses, and granular aggregates.

Elongation: (0001), lath-shaped. (+).

Red, yellowish, yellowish gray.

Pleochroism:  $O$  = brownish red,  $E$  = light yellowish red.

$\omega = 3.22$ ,  $\varepsilon = 2.94$ .

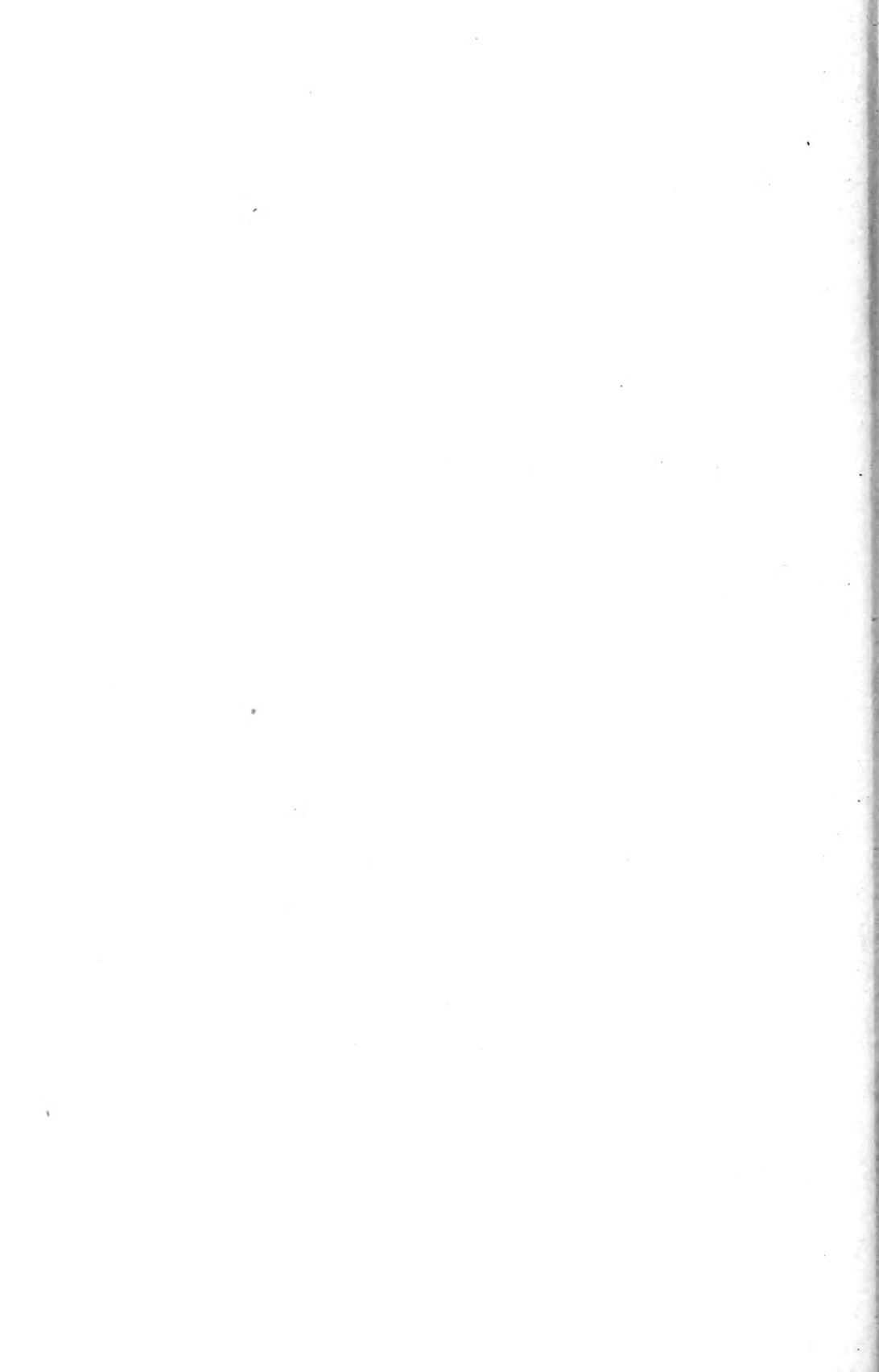
$\omega - \varepsilon = 0.28$ .

Very slowly soluble in HCl.

**Magnetite** is magnetic and soluble in HCl.

**Limonite** may be confused with hematite.

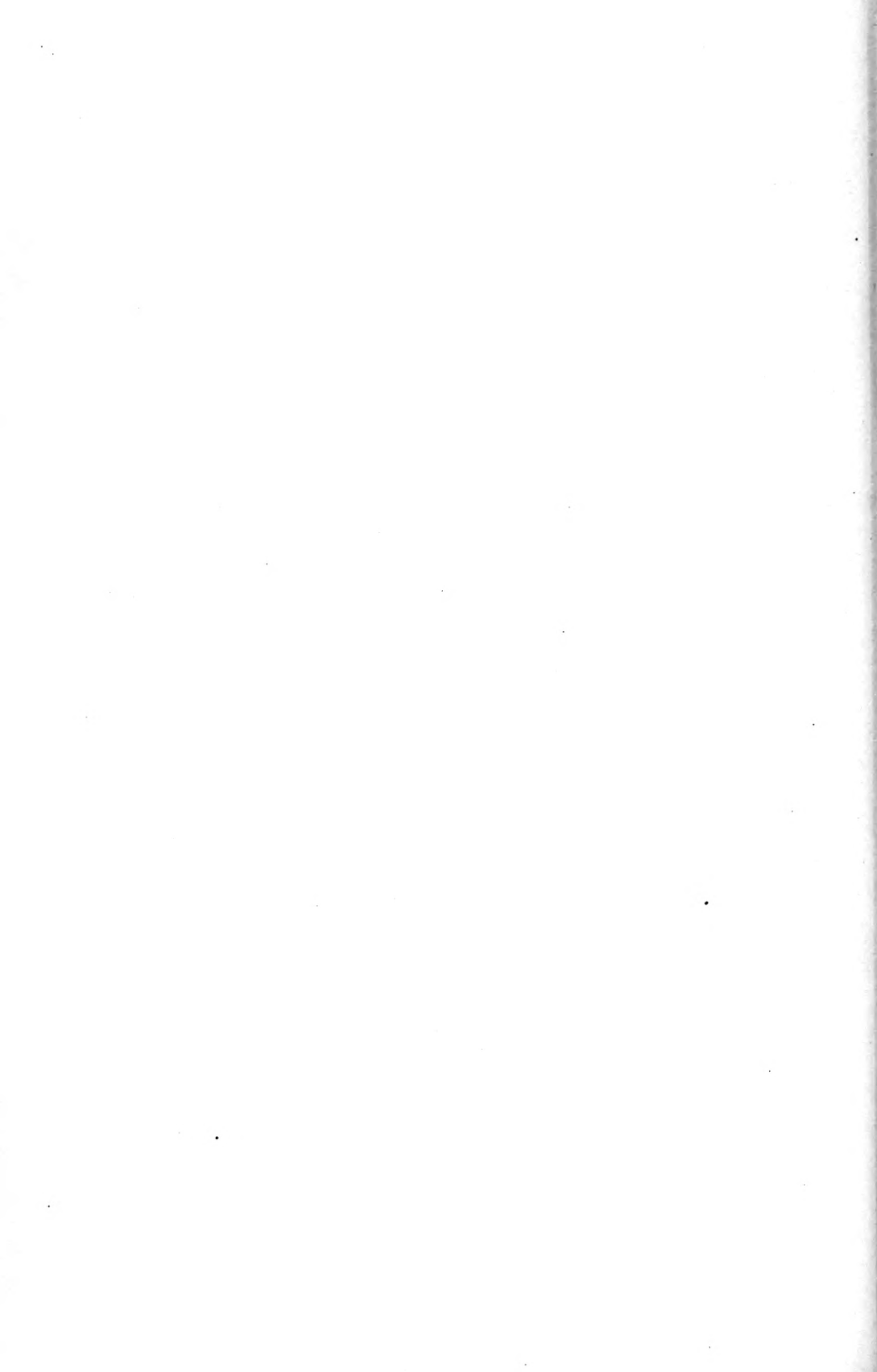
Cut on line.





**Rutile.**—  $\text{TiO}_2$ ,  $H = 6.0-6.5$ ,  $G = 4.2-4.3$ .  
 Tetragonal. (+).  
 Cleavage: (110), (100), good to fair.  
 Habit: Prisms, grains, geniculated and heart-shaped twins, sagenite webs.  
 Elongation: (110):(1 $\bar{1}$ 0), prismatic. (+).  
 Yellow, fox-red, violet.  
 Pleochroism: Seldom noticeable;  $O$ =yellowish to brownish,  $E$ =brownish yellow to greenish yellow.  
 $\omega = 2.616$ ,  $\varepsilon = 2.903$ .  
 $\omega - \varepsilon = 0.2871$ .  
 Insoluble in acids.  
**Cassiterite** and **zircon** have lower double refraction and different chemical reactions.  
**Anatase**, **brookite**, and **pseudobrookite** differ in crystal form and cleavage.  
**Perovskite** contains Ca.

Cut on line.



The mineral is **anisotropic**.

**Parallel extinction.**

**Colored.**

**Pleochroic.**

**Maximum birefringence is greater  
than that of quartz.**

**Biaxial.**

**BIAXIAL.**

*Cut on line.*



**Cordierite.**— $\text{Mg}_2\text{Al}_4\text{Si}_5\text{O}_{18}$ ,  $H = 7.0-7.5$ ,  $G = 2.59-2.66$ .

Orthorhombic. (—).

Cleavage: (010), poor.

Habit: Grains, short prisms. Trillings and polysynthetic twins occur.

Elongation: (110), ( $\bar{1}\bar{1}0$ ), short laths. (—).

Orientation:  $b = c$ ,  $c = a$ .

Colorless, bluish, yellowish.

Pleochroism: Wanting or weak with  $b > c > a$ .

$\alpha = 1.535$ ,  $\beta = 1.540$ ,  $\gamma = 1.544$ .

$\gamma - \alpha = 0.009$ ,  $\gamma - \beta = 0.004$ ,  $\beta - \alpha = 0.005$ .

Dispersion: Weak,  $\rho < \nu$ .

$2E = 63^\circ-150^\circ$ .

When treated with HF gives characteristic prismatic crystals of magnesium fluosilicate.

**Quartz** has higher interference colors, is uniaxial, and (+). Chemically different, reactions as above.

**Dumortierite.**— $3(\text{Al}_8\text{Si}_3\text{O}_{18}) \cdot \text{AlB}_3\text{O}_6 \cdot 2\text{H}_2\text{O}$ ,  $H = 7.0$ ,  $G = 3.22-3.36$ .

Orthorhombic. (—).

Cleavage: (100), good.

Habit: Prisms, needles.

Elongation: (110):(1 $\bar{1}$ 0), long lath-shaped. (—).

Orientation:  $a = c$ ,  $c = a$ .

Blue, brownish, greenish, colorless.

Pleochroism:  $a = \text{blue}$ ;  $b = \text{yellowish, reddish violet, greenish}$ ;  $c = \text{colorless}$ .

$\alpha = 1.678$ ,  $\beta = 1.686$ ,  $\gamma = 1.689$ .

$\gamma - \alpha = 0.011$ ,  $\gamma - \beta = 0.003$ ,  $\beta - \alpha = 0.008$ .

Dispersion:  $\rho > \nu$ .

$2V = 30^\circ$ .

Insoluble in HF and other acids.

**Blue amphibole** is monoclinic.

**Serendibite** is triclinic, extinction  $40^\circ$  ca.

**Sapphire** is monoclinic with  $c : c = 8^\circ-9^\circ$ .

**Grandidierite** has different habit,  $a = a$ ,  $b = c$ , and strong blue-green to colorless pleochroism.

**Andalusite.**— $\text{Al}_2\text{SiO}_5$ ,  $H = 7.5$ ,  $G = 3.10-3.20$ .

Orthorhombic. (—).

Cleavage: (110), good. (110):(1 $\bar{1}$ 0) =  $89^\circ$ .

Habit: Prisms, grains.

Elongation: (110):(1 $\bar{1}$ 0), lath-shaped. (—).

Orientation:  $a = c$ ,  $c = a$ .

Colorless, reddish.

Pleochroism:  $a = \text{rose}$ ;  $b = c = \text{colorless to light green}$ .

*Cut on line.*



$\alpha = 1.632$ ,  $\beta = 1.638$ ,  $\gamma = 1.643$ .

$\gamma - \alpha = 0.011$ ,  $\gamma - \beta = 0.005$ ,  $\beta - \alpha = 0.006$ .

$2V = 84^\circ - 85^\circ$ .

Not attacked by HF or other acids.

**Sillimanite** is (+), has basal cleavage, and has higher double refraction.

**Topaz** has perfect basal cleavage and is (+).

**Scapolites** have higher double refraction in prisms and are uniaxial.

**Zoisite** has (010) and (100) cleavage, and is (+);  $2V = 0^\circ - 60^\circ$ .

**Thulite** is (+),  $2V = 0^\circ - 40^\circ$ .

**Orthoclase** has lower indices of refraction.

**Prismatine** has  $2E = 65.5^\circ$ .

**Cornerupine** has  $2E = 14^\circ - 32^\circ$ .

**Delessite.**— $\text{H}_{10}(\text{Mg}, \text{Fe})_4(\text{Al}, \text{Fe})_4\text{Si}_4\text{O}_{23}$ ,  $H = 2.5$ ,  $G = 2.5 - 3.0$ .

Monoclinic. (—).

Cleavage: (001), good.

Habit: Scales, spherulitic aggregates.

Elongation: At right angles to (001), lath-shaped. (+).

Orientation:  $b = \mathfrak{b}$ ,  $c: \mathfrak{a}$  = very small to  $0^\circ$ .

Green, yellow, brown.

Pleochroism:  $\mathfrak{a}$  = yellowish to colorless,  $\mathfrak{c}$  and  $\mathfrak{b}$  = green.

Index: Similar to clinochlore, in which  $\alpha = 1.585$ ,  $\beta = 1.586$ ,  $\gamma = 1.596$ .

Birefringence: Similar to clinochlore, in which  $\gamma - \alpha = 0.011$ ,  $\gamma - \beta = 0.010$ ,  $\beta - \alpha = 0.001$ .

Gelatinizes easily with acids.

**Other minerals:** Its resemblance to chlorite separates delessite from other minerals.

**Clinochlore** is (+).

**Hypersthene.**— $(\text{Fe}, \text{Mg})\text{SiO}_3$ ,  $H = 5.0 - 6.0$ ,  $G = 3.40 - 3.50$ .

Orthorhombic. (—).

Cleavage: (010), distinct; (100), good; (110), good.  $(110):(1\bar{1}0) = 91^\circ 40'$ .

Habit: Prismatic, often massive.

Elongation:  $(110):(1\bar{1}0)$ , lath-shaped. (+).

Orientation:  $b = \mathfrak{a}$ ,  $c = \mathfrak{c}$ .

Colorless, yellowish, reddish.

Pleochroism:  $\mathfrak{c}$  = greenish,  $\mathfrak{a}$  = reddish yellow,  $\mathfrak{b}$  = reddish brown. Strong.

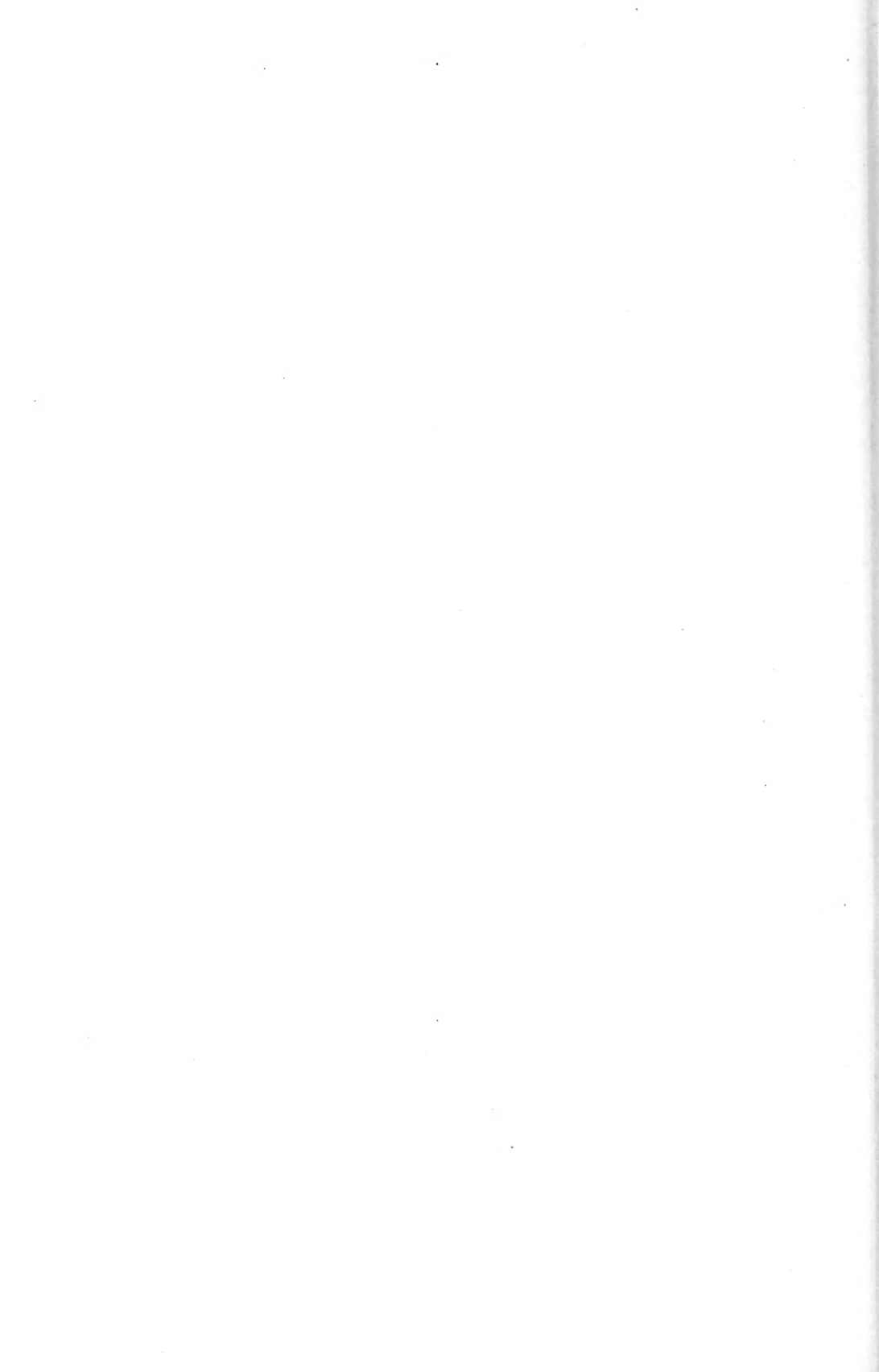
$\alpha = 1.692$ ,  $\beta = 1.702$ ,  $\gamma = 1.705$ .

$\gamma - \alpha = 0.013$ ,  $\gamma - \beta = 0.003$ ,  $\beta - \alpha = 0.010$ .

Dispersion:  $\rho > \nu$ .

$2E = 85^\circ$  ca.

*Cut on line.*





Partially decomposed by HCl.

**Bronzite** is (+) and has weaker pleochroism.

**Monoclinic pyroxenes** have inclined extinction and higher double refraction. Basal sections showing cleavage give the emergence of an axis, while orthorhombic pyroxenes show the emergence of a positive bisectrix. See also Part II.

**Ægirite** has different pleochroism, green to yellowish green, has higher double refraction, and has (−) elongation.

**Glaucophane.**— $\text{NaAl}(\text{SiO}_3)_2 \cdot (\text{Fe}, \text{Mg})\text{SiO}_3$ ,  $H = 6.0-6.5$ ,  $G = 3.103-3.113$ .

Monoclinic. (−).

Cleavage: (110), good; (100), distinct; (010), poor. (110):(110) =  $55^\circ 16'$ .

Habit: Short prisms, grains. Twinning (100).

Elongation: (110):(110), lath-shaped. (+).

Orientation:  $b = \mathfrak{h}$ ,  $c: \mathfrak{r} = -4^\circ$  to  $-6^\circ$ .

Blue, violet, yellowish green, almost colorless.

Pleochroism:  $\mathfrak{a}$  = nearly colorless to yellowish green.  $\mathfrak{h}$  = reddish to bluish violet,  $\mathfrak{r}$  = blue.

$\alpha = 1.621$ ,  $\beta = 1.638$ ,  $\gamma = 1.639$ .

$\gamma - \alpha = 0.018$ ,  $\gamma - \beta = 0.001$ ,  $\beta - \alpha = 0.017$ .

Dispersion: Strong,  $\rho < \nu$ .

$2E = 85.5^\circ$ .  $2V_{\mathfrak{aa}} = 43^\circ 58'$ .

One of the amphiboles.

But slightly affected by acids.

**Other minerals** which resemble it differ in cleavage, pleochroism, and have (−) elongation.

**Gedrite.**— $(\text{Mg}, \text{Fe})\text{SiO}_3$  and  $(\text{Mg}, \text{Fe})\text{Al}_2\text{SiO}_6$ ,  $H = 5.5-6.0$ ,  $G = 3.1-3.2$ .

Orthorhombic. (−).

Cleavage: (110), good; (100), distinct; (010), poor. (110):(110) =  $55^\circ 12'$ .

Habit: Rods, leaves, grains.

Elongation: (110):(110), lath-shaped. (+).

Orientation:  $a = \mathfrak{a}$ ,  $c = \mathfrak{r}$ .

Colorless, yellowish, brownish, greenish.

Pleochroism:  $\mathfrak{r}$  = yellowish, greenish;  $\mathfrak{h}$  = clove-brown, reddish;

$\mathfrak{a}$  = yellowish, greenish, colorless.

$\alpha = 1.623$ ,  $\beta = 1.636$ ,  $\gamma = 1.644$ .

$\gamma - \alpha = 0.021$ ,  $\gamma - \beta = 0.008$ ,  $\beta - \alpha = 0.013$ .

Dispersion:  $\rho > \nu$ .

$2V = 79^\circ-57^\circ$ .

Not affected by acids.

One of the orthorhombic pyroxenes.

**Other amphiboles.** See Part II.

Cut on line.



Carpholite —  $\text{H}_4\text{MnAl}_2\text{Si}_2\text{O}_{10}$ ,  $H = 5.0-5.5$ ,  $G = 2.935$ .

Monoclinic. (—).

Cleavage: Unnoticeable.

Habit: Rods, fibres.

Elongation:  $(110):(1\bar{1}0)$ , narrow laths. (+).

Orientation:  $b = a$ ,  $c: a = 4^\circ$  ca.

Colorless, greenish yellow.

Pleochroism: Distinct,  $c$  = colorless,  $a = b$  = yellowish green.

Index:  $n = 1.627$ .

$\gamma - \alpha = 0.022$ .

$2V = 60^\circ$ .

Insoluble in acids.

**Rosenbuschite** is soluble in acids, elongation (—),  $2V = 90^\circ$ , cleavage (001), good.

**Sillimanite** is (+), non-pleochroic, good (100) cleavage.

**Pistacite**.—(Epidote),  $\text{Al}(\text{SiO}_4)_3(\text{Al}, \text{Fe})_2\text{Ca} \cdot \text{CaOH}$ ,  $H = 6.5$ ,  $G = 3.3-3.5$ .

Monoclinic. (—).

Cleavage: (001), good; (100), distinct.  $(001):(100) = 64^\circ 37'$ .

Habit: Prisms and rods elongated along  $b$ , grains; twins (100).

Elongation:  $(001):(100)$ , lath-shaped. ( $\pm$ ).

Orientation:  $b = b$ ,  $c: a = +3^\circ$ .

Green, yellow, brownish, colorless.

Pleochroism:  $a$  = colorless to yellowish or greenish,  $b$  = yellowish to yellowish gray, lavender;  $c$  = green, light yellowish brown.

$\alpha = 1.714$ ,  $\beta = 1.741$ ,  $\gamma = 1.746$ .

$\gamma - \alpha = 0.032$ ,  $\gamma - \beta = 0.005$ ,  $\beta - \alpha = 0.027$ .

Dispersion:  $\rho > \nu$ .

$2V = 74^\circ-90^\circ$ .

Not affected by HCl.

Pistacite is the Fe-rich epidote, clinozoisite the Fe-poor or free.

**Pyroxene** has (110) cleavage; in sections parallel to the long direction the plane of the optic axes is parallel to the cleavage; in epidote at right angles to it.

**Clinozoisite** has lower double refraction, is (+), has strong  $\rho < \nu$  dispersion.

**Piedmontite**.— $\text{Al}(\text{SiO}_4)_3(\text{Al} \cdot \text{Mn} \cdot \text{Fe})_2\text{Ca} \cdot \text{CaOH}$ ,  $H = 6.5$ ,  $G = 3.40$ .

Monoclinic. (—). Mn-rich piedmontite is (+).

Cleavage: (001), good; (100) distinct.  $(001):(101) = 63^\circ 30.5'$ .

Habit: Prisms, rods elongated along  $b$ , grains.

Elongation:  $(001):(100)$ , lath-shaped. ( $\pm$ )

Orientation:  $b = b$ ,  $c: a = +5^\circ$  to  $+6^\circ$ .

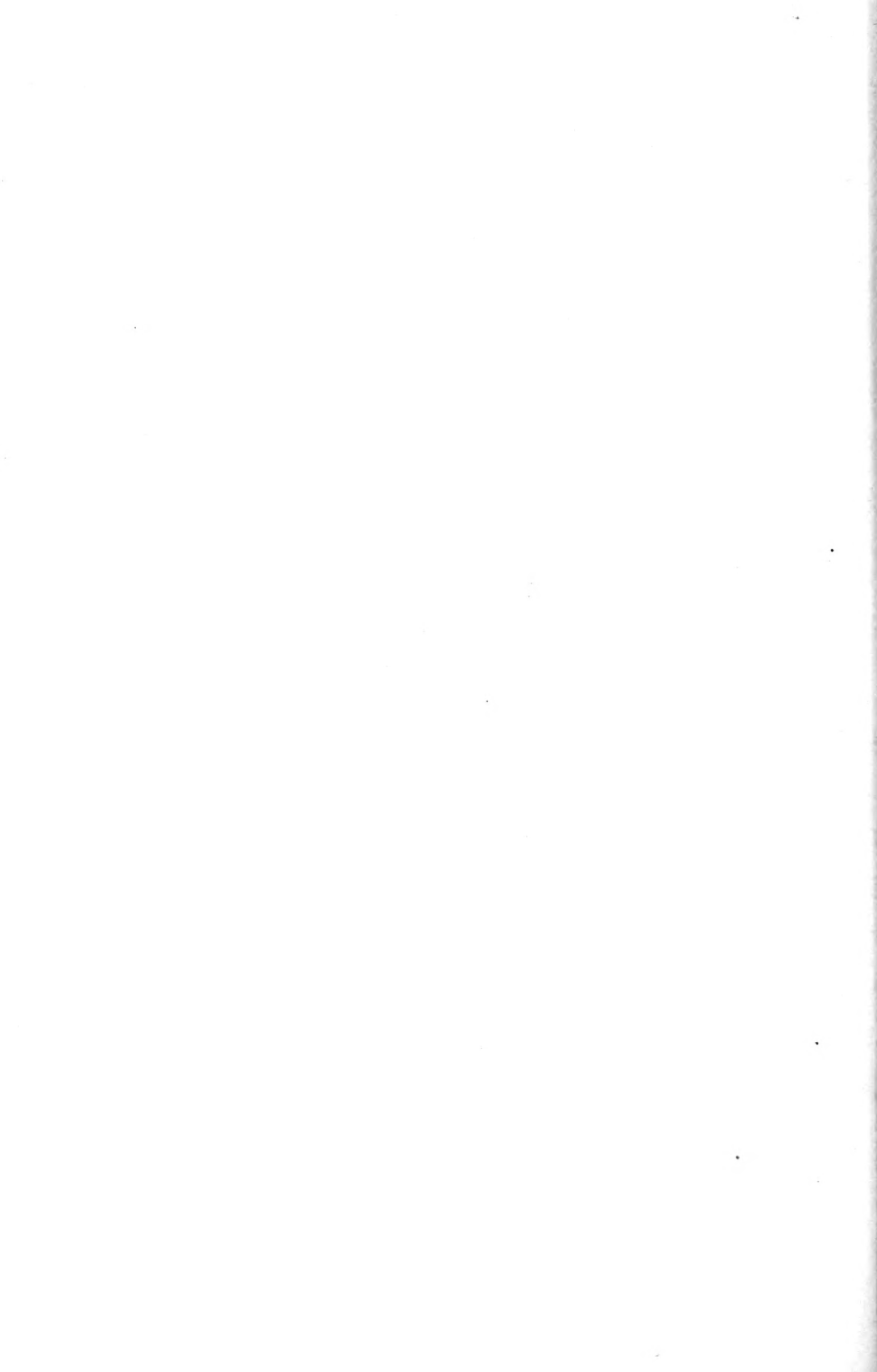
Red, yellow, colorless.

Pleochroism: Strong and characteristic;  $a$  = orange;  $b$  = violet, amethyst;  $c$  = red.

Indices similar to pistacite.

Birefringence similar to pistacite.

Cut on line.



$2V=90^\circ$ . It becomes greater than  $90^\circ$  in the Mn-rich piedmontites, and the mineral becomes optically (+).

Insoluble in HCl.

**Pistacite, clinozoisite, and orthite** have different pleochroism.

**Other minerals** are separated by the epidote-like character of piedmontite.

**Grandierite.**—Al, Mg, Na, Fe, Ca silicate, H = unknown, G = 2.99.

Orthorhombic. (—).

Cleavage: (100), (010), good.

Habit: Cloudy masses and poikilitic with quartz.

Orientation:  $a = \mathfrak{a}$ ,  $b = \mathfrak{c}$ .

Blue, green.

Pleochroism: Strong,  $\mathfrak{a}$  = blue-green;  $\mathfrak{b}$  = colorless;  $\mathfrak{c}$  = pale bluish green.

$\alpha = 1.602$ ,  $\beta = 1.636$ ,  $\gamma = 1.639$ .

$\gamma - \alpha = 0.037$ ,  $\gamma - \beta = 0.003$ ,  $\beta - \alpha = 0.034$ .

Dispersion:  $\rho > \nu$ .

$2E = 50^\circ$ .

Insoluble in acids.

**Sapphirine** has no cleavage, is monoclinic with  $8^\circ$  extinction, and has 0.005 for maximum birefringence.

**Biotite.**—Mg, Fe, Al silicate, H = 2.5–3.0, G = 2.8–3.2.

Monoclinic, often appears uniaxial. (—).

Cleavage: (001), good.

Habit: Leaves, leafy aggregates.

Elongation: At right angles to (001), lath-shaped. (+).

Orientation:  $b = \mathfrak{b}$ ,  $c: \mathfrak{a} = 0^\circ$  to  $+7^\circ$ .

Brown, green, yellow.

Pleochroism: Strong,  $\mathfrak{c} \gtrsim \mathfrak{b} > \mathfrak{a}$ ;  $\mathfrak{c}$  and  $\mathfrak{b}$  = deep brown to red-brown, deep green to black;  $\mathfrak{a}$  = light yellow to red, light green.

$\alpha = 1.557$ ,  $\beta = 1.589$ ,  $\gamma = 1.597$ .

$\gamma - \alpha = 0.040$ ,  $\gamma - \beta = 0.008$ ,  $\beta - \alpha = 0.032$ .

Dispersion: Weak,  $\rho \gtrsim \nu$ .

$2E = 0^\circ$  to  $72^\circ$ .

Soluble in  $\text{H}_2\text{SO}_4$  and the Fe-rich biotites in HCl with separation of  $\text{SiO}_2$  scales.

**Minerals other than micas**, see Part II.

**Alkali micas** have different color, pleochroism, larger  $2V$ , different position of the plane of the optic axes, and are different chemically.

**Anomite** has different position of the plane of the optic axes.

**Lithionite**, when dark in color, may be separated by the Li reaction.

**Anomite.**—Under anomite, following Rosenbusch, are included those rock-forming biotites which have the plane of the optic axes at right angles to the symmetry plane. See Part II.

H = 2.5–3.0,

G = 2.8–3.2.

Cut on line.



Monoclinic. (-).

Cleavage: Good, (001).

Habit: Leaves, leafy aggregates.

Elongation: At right angles to (001), lath-shaped. (+).

Orientation:  $b = c$ ,  $c : a = 0^\circ$  to  $+4^\circ$ .

Brown, green, yellow.

Pleochroism: Very strong, like biotite.  $c > b > a$ .

Indices: Like biotite.

Birefringence: Like biotite.

Dispersion: Weak,  $\rho \gtrsim \nu$ .

$2E = 10^\circ - 68^\circ$ .

Biotite has  $b = b$ .

Other micas, see biotite.

Other minerals than micas, see Part II.

**Zinnwaldite.**—K, Li, Fe, Al silicate,  $H = 2.5 - 3.0$ ,  $G = 2.82 - 3.20$ .

Monoclinic. (-).

Cleavage: (001), good.

Habit: Leaves, leafy aggregates.

Elongation: At right angles to (001), lath-shaped. (+).

Orientation:  $b = b$ ,  $c : a = 0^\circ$  to  $+7^\circ$ .

Brown, red, yellow, rarely green.

Pleochroism: Strong,  $c > b > a$ ;  $c$  and  $a$  = dark brown, brownish gray;  $b$  = yellowish brown or reddish, nearly colorless.

Indices are similar to biotite.

Birefringence is similar to biotite.

Dispersion: Weak,  $\rho > \nu$ .

$2E = 10^\circ - 60^\circ$ .

Lepidolite has different position of the plane of the optic axes.

Other micas, see biotite.

Other minerals than mica, see Part II.

**Phlogopite.**—A magnesium mica, near biotite, but containing little Fe,  $H = 2.5 - 3.0$ ,  $G = 2.78 - 2.85$ .

Monoclinic. (-).

Cleavage: (001), good.

Habit: Leaves, leafy aggregates.

Elongation: At right angles to (001), lath-shaped. (+).

Orientation:  $b = b$ ,  $c : a = 0^\circ$  to  $+7^\circ$ .

Colorless, yellowish, brownish, greenish.

Pleochroism: Weak with  $c > b > a$ .

$\alpha = 1.562$ ,  $\beta = 1.606$ ,  $\gamma = 1.606$ .

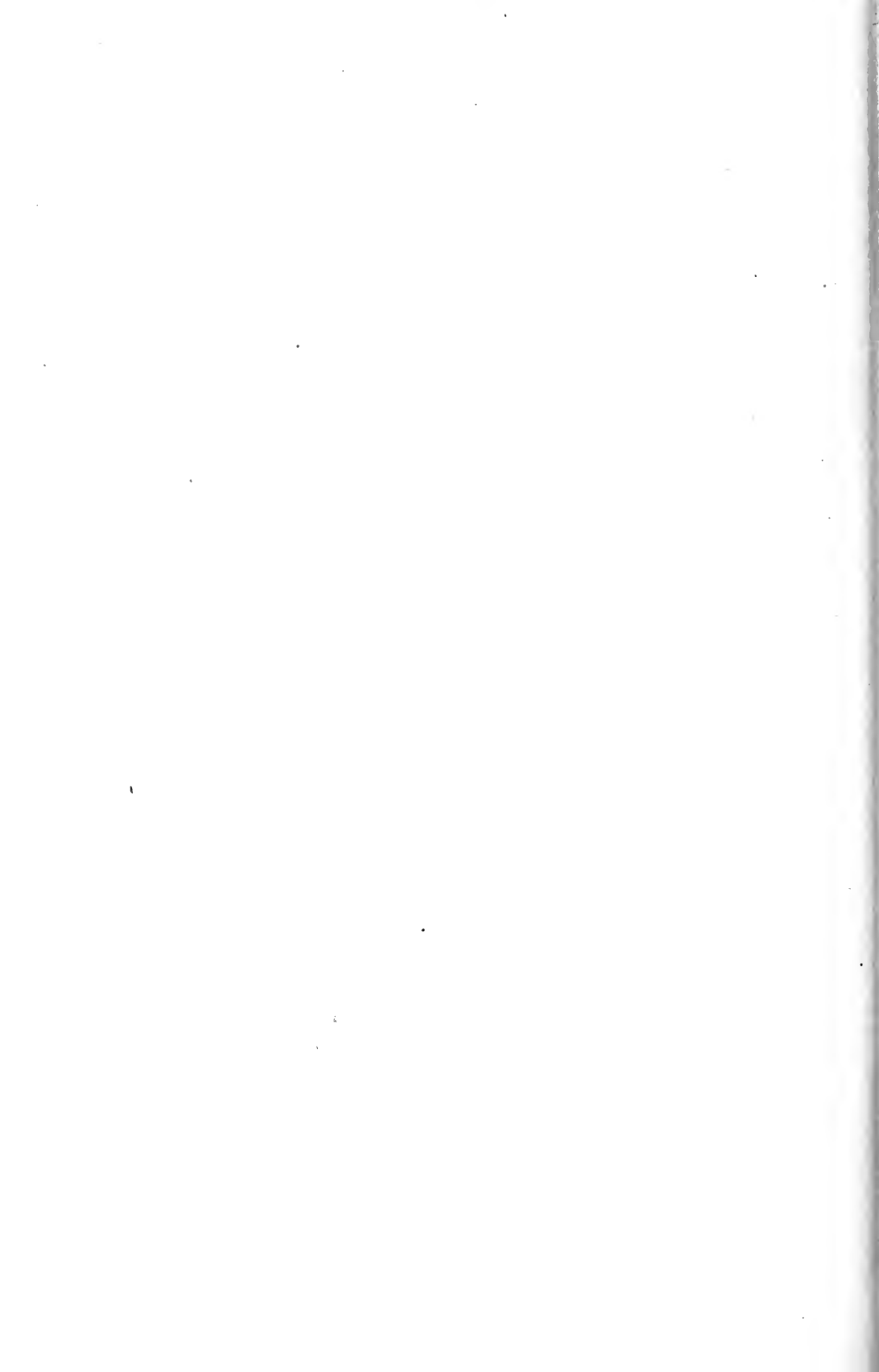
$\gamma - \alpha = 0.044$ ,  $\gamma - \beta = 0.0$ ,  $\beta - \alpha = 0.044$ .

Dispersion: Weak,  $\rho < \nu$ .

$2E = \text{small to } 0^\circ$ .

Completely decomposed by  $H_2SO_4$ , leaving the silica in thin flakes. One of the micas.

Cut on line.





**Other micas:** Phlogopite has small to very small  $2V$ , and has symmetrical position of the plane of the optic axes.

**Other minerals,** see Part II.

**Fayalite.**—  $\text{Fe}_2\text{SiO}_4$ ,  $H=6.5-7.0$ ,  $G=4.1$ .

Orthorhombic. (—).

Cleavage: (100), poor.

Habit: Isometric, short prisms, grains.

Orientation:  $a=c$ ,  $b=a$ .

Greenish, yellowish, red, colorless.

Pleochroism: Wanting or weak in yellow and red tones.

$\alpha=1.824$ ,  $\beta=1.864$ ,  $\gamma=1.874$ .

$\gamma-\alpha=0.050$ ,  $\gamma-\beta=0.010$ ,  $\beta-\alpha=0.040$ .

Dispersion: Distinct,  $\rho > \nu$ .

$2V=50^\circ$  ca.

An iron-rich olivine.

Gelatinizes quite easily with HCl.

**Olivine** has  $2V=88^\circ$ , is (+), and has lower birefringence.

**Forsterite** is (+), has  $2V=86^\circ$ , has lower indices, and different occurrence.

**Monticellite** has  $2V=37.5^\circ$ , has lower indices and lower double refraction.

See also Olivine group, Part II.

**Ægirite.**—  $\text{NaFeSi}_2\text{O}_6$ ,  $H=6.0-6.5$ ,  $G=3.5-3.6$ .

Monoclinic. (—).

Cleavage: (110), good.  $(110):(1\bar{1}0)=92^\circ 49'$ .

Habit: Thin prisms, needles. Crystals bluntly terminated.

Elongation:  $(110):(1\bar{1}0)$ , lath-shaped. (—).

Orientation:  $b=b$ ,  $c:a=3^\circ$  to  $6^\circ$ .

Green, yellow, brown.

Pleochroism:  $a$ =deep green;  $b$ =lighter green to yellowish green;

$c$ =yellow to brownish.

$\alpha=1.763$ ,  $\beta=1.799$ ,  $\gamma=1.813$ .

$\gamma-\alpha=0.050$ ,  $\gamma-\beta=0.014$ ,  $\beta-\alpha=0.036$ .

Dispersion:  $\rho > \nu$ . Strong dispersion of bisectrices;  $c:a_\rho < c:a_\nu$ .

$2V=62^\circ$ .

A pyroxene. Attacked with difficulty by acids.

**Other pyroxenes.** Ægirite has small extinction angle  $c:a$ .

See also Part II.

**Acmite** has sharp-pointed crystals.

**Acmite.**—  $\text{NaFeSi}_2\text{O}_6$ ,  $H=6.0-6.5$ ,  $G=3.5-3.6$ .

Monoclinic. (—).

Cleavage: (110), good.  $(110):(1\bar{1}0)=92^\circ 56'$ .

Habit: Thin prisms, laths, needles. Sharp-pointed crystals.

Elongation:  $(110):(1\bar{1}0)$ , lath-shaped. (—).

Orientation:  $b=b$ ;  $c:a=3^\circ$  to  $6^\circ$ .

Cut on line.



Brown, yellow.

Pleochroism:  $a$ =brown;  $b$ =light brown;  $c$ =greenish yellow.

Indices: Like ægirite.

Birefringence: Like ægirite.

Dispersion: Strong inclined,  $\rho > \nu$  around  $a$ .

A rare pyroxene.

Ægirite has different pleochroism.

Other pyroxenes: Like ægirite. See also Part II.

Ægirite occurs in bluntly terminated crystals.

**Iddingsite.**—Fe, Ca, Mg, Na silicate. Perhaps antigorite intergrown with hematite,  $H=2.5$ ,  $G=2.839$ .

System: Biaxial. (—).

Cleavage: (100), good.

Habit: Pseudomorphs after olivine.

Orientation:  $a = a$ ,  $c = c$ .

Red-brown, green.

Pleochroism:  $a$ =brown, red, yellow, also yellowish green.

$b = c$ =greenish, yellowish.

Index: Not marked.

Birefringence: Strong.

$2E$ =small to very small.

Other minerals: Iddingsite may be distinguished by its habit, cleavage, and (—) character.

Hematite shows no cleavage and is uniaxial.

**Basaltic Hornblende.**—Ca, Mg, Fe, Al silicate,  $H=5.5-6.0$ ,  $G=3.05-3.47$ .  
Monoclinic. (—).

Cleavage: (110), good; (100), distinct; (010), poor. (110):(110) =  $55.5^\circ$ .

Habit: Short prisms, grains.

Elongation: (110):(110), lath-shaped. (+).

Orientation:  $b = b$ ,  $c: c = 0^\circ$  to  $-12^\circ$ .

Brown.

Pleochroism: Strong in brown and yellow tones with  $c > b > a$ , also in green and brown tones with  $a$ =green,  $b$  and  $c$ =brown.

$\alpha = 1.680$ ,  $\beta = 1.725$ ,  $\gamma = 1.752$ .

$\gamma - \alpha = 0.072$ ,  $\gamma - \beta = 0.027$ ,  $\beta - \alpha = 0.015$ .

$2V = 80^\circ$ .

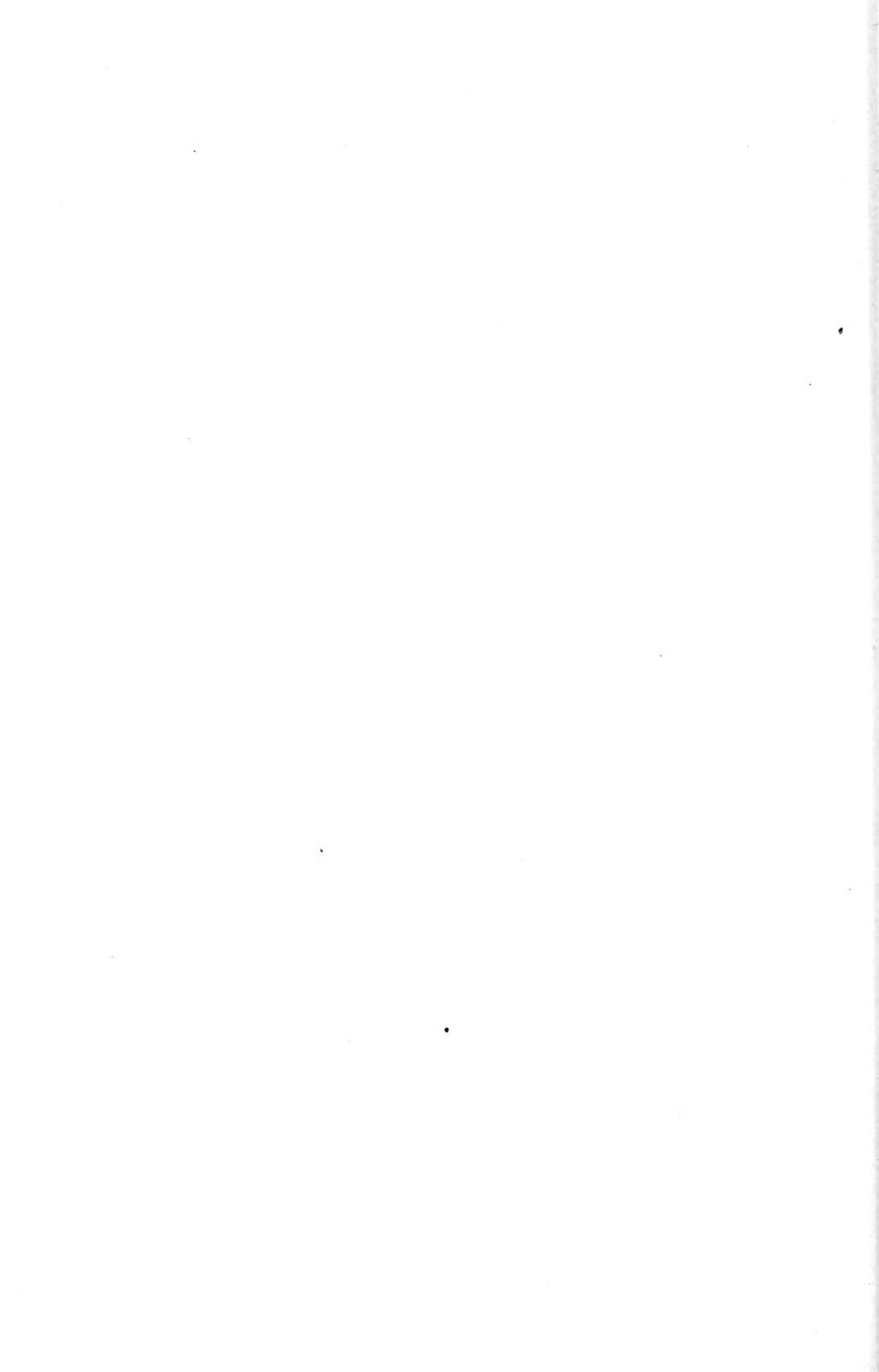
But slightly acted upon by HCl.

An amphibole.

Other amphiboles and pyroxenes, see Part II.

Common hornblende has  $c: c = -12^\circ$  to  $-20^\circ$ , sometimes (+) character, lower double refraction, and sometimes lower  $2V$ .

Mica generally had a peculiar "bird's-eye maple" appearance.



**Bronzite.**— $(\text{Mg, Fe})_2\text{Si}_2\text{O}_6$ ,  $H=5.0-6.0$ ,  $G=3.29$ .  
 Orthorhombic. (+).  
 Cleavage: (010), distinct; (100), good; (110), good.  $(110):(1\bar{1}0)=91^\circ 40'$ .  
 Habit: Prismatic, cloudy masses. Geniculated and star-shaped twins occur rarely.  
 Elongation:  $(110):(1\bar{1}0)$ , lath-shaped. (+).  
 Orientation:  $b=a$ ,  $c=c$ .  
 Colorless, yellowish, reddish.  
 Pleochroism: Weak:  $c$ =greenish;  $a$ =reddish yellow;  $b$ =reddish brown.  
 $\alpha=1.665$ ,  $\beta=1.669$ ,  $\gamma=1.674$ .  
 $\gamma-\alpha=0.009$ ,  $\gamma-\beta=0.005$ ,  $\beta-\alpha=0.004$ .  
 Dispersion:  $\rho < \nu$ .  
 $2E=106^\circ$  ca.  $2V=80^\circ$ .

An orthorhombic pyroxene.

**Hypersthene** has same pleochroism, strong, and is (-).

**Monoclinic pyroxenes**, see Part II, also under enstatite above.

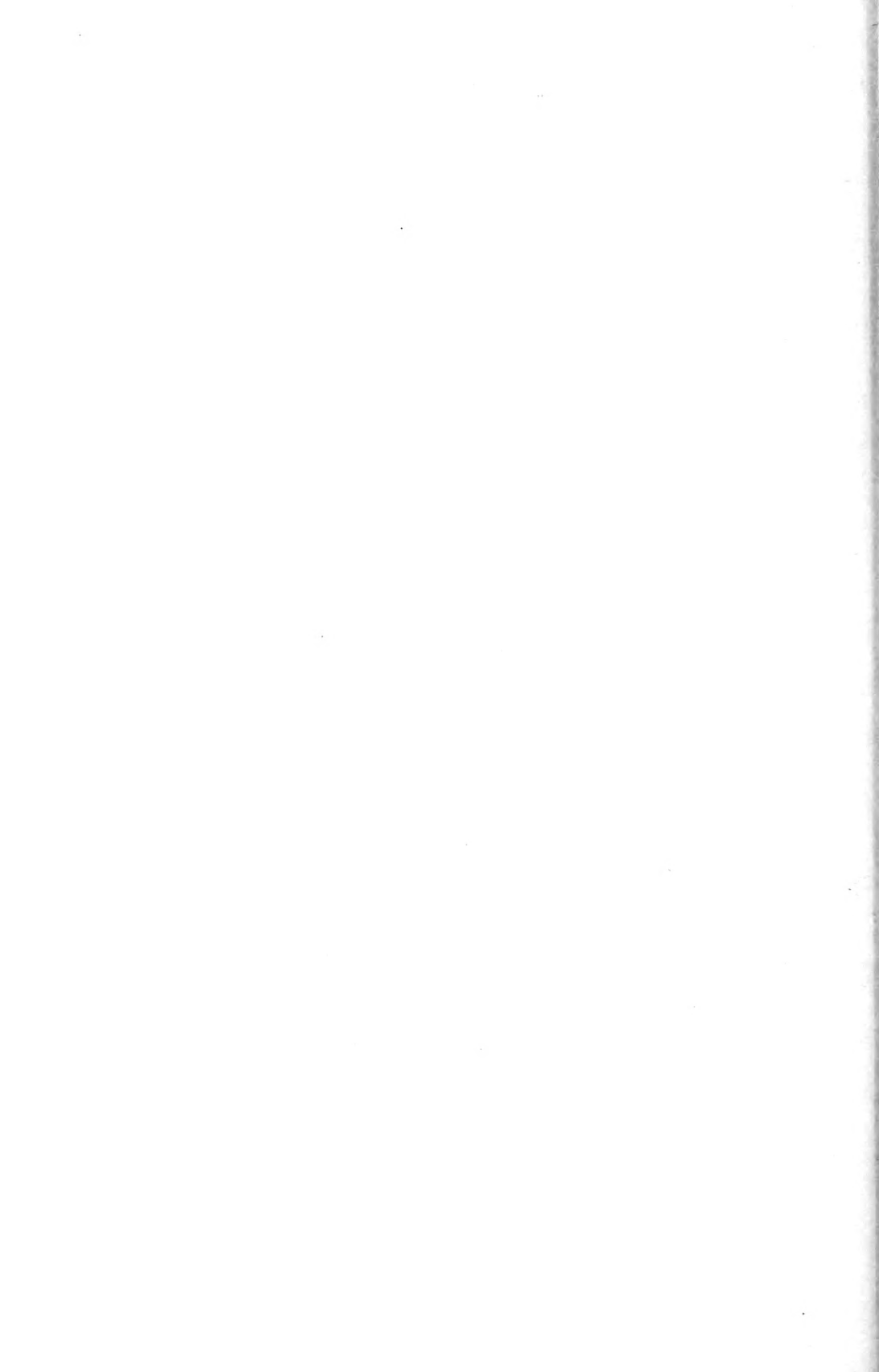
**Staurolite.**— $\text{HFeAl}_2\text{Si}_2\text{O}_{13}$ ,  $H=7.0-7.5$ ,  $G=3.65-3.8$ .  
 Orthorhombic. (+).  
 Cleavage: (010), distinct.  
 Habit: Short prisms. Often crossed twins.  
 Elongation:  $(110):(1\bar{1}0)$ , short laths. (+).  
 Orientation:  $b=a$ ,  $c=c$ .  
 Yellow, red-brown.  
 Pleochroism:  $c$ =red;  $a=b$ =yellow.  
 $\alpha=1.736$ ,  $\beta=1.741$ ,  $\gamma=1.746$ .  
 $\gamma-\alpha=0.010$ ,  $\gamma-\beta=0.005$ ,  $\beta-\alpha=0.005$ .  
 Dispersion: Weak,  $\rho > \nu$ .  
 $2V=89^\circ$ .

Insoluble in cold  $\text{HF}$  or other acids.

**Bronzite** has larger  $2V$ , weak pleochroism.

**Clinocllore.**— $\text{Mg, Fe, Al silicate}$ ,  $H=2.0-2.5$ ,  $G=2.71$ .  
 Monoclinic. (+).  
 Cleavage: (001), good.  
 Habit: Leaves, scales, leafy aggregates. Twinning common.  
 Elongation: At right angles to (001), lath-shaped. (-).  
 Orientation:  $b=b$ ,  $c:c=-2^\circ$  to  $-9^\circ$ .  
 Green.  
 Pleochroism:  $a$  and  $b$ =green;  $c$ =yellow.  
 $\alpha=1.585$ ,  $\beta=1.586$ ,  $\gamma=1.596$ .  
 $\gamma-\alpha=0.011$ ,  $\gamma-\beta=0.010$ ,  $\beta-\alpha=0.001$ .  
 Dispersion:  $\rho < \nu$ .  
 $2E=32^\circ-90^\circ$ .

**Pennine** is ( $\pm$ ),  $2E=0^\circ-61^\circ$ ,  $c:c=0^\circ$ ,  $\gamma-\alpha=0.002$ .



**Anthophyllite.**—(Mg,Fe)SiO<sub>3</sub>,                      H = 5.5-6.0,                      G = 3.1-3.2.  
 Orthorhombic. (±).  
 Cleavage: (110), good; (100), distinct; (010), poor. (110):(110) = 54° 23'.  
 Habit: Rods, leaves, grains.  
 Elongation: (110):(110), lath-shaped. (+).  
 Orientation:  $a = a$ ,  $c = c$ .  
 Colorless, yellowish, brownish, greenish  
 Pleochroism:  $c$  = yellowish, brownish;  $b$  = clove-brown, reddish;  $a$  = yellowish, greenish, colorless.  
 $\alpha = 1.633$ ,  $\beta = 1.642$ ,  $\gamma = 1.657$ .  
 $\gamma - \alpha = 0.024$ ,  $\gamma - \beta = 0.015$ ,  $\beta - \alpha = 0.009$ .  
 Dispersion:  $\rho > \nu$ ,  $\rho < \nu$ .  
 $2V \geq 90^\circ$ .  
 Unacted upon by acids.  
 An orthorhombic amphibole.  
 Other amphiboles, see Part II.

Manganese-rich piedmontite, see piedmontite above.

**Olivine.**—(Mg,Fe)SiO<sub>3</sub>,                      H = 6.5-7.0,                      G = 3.27-3.45.  
 Orthorhombic. (+).  
 Cleavage: (010), (001), distinct; (100), poor. Generally shows heavy irregular cracks.  
 Habit: Isometric, short prisms, grains; twins (011) and (012), rare.  
 Orientation:  $a = c$ ,  $b = a$ .  
 Greenish, yellowish, reddish, colorless.  
 Pleochroism: Wanting or weak in yellow and red tones.  
 $\alpha = 1.654$ ,  $\beta = 1.670$ ,  $\gamma = 1.689$ .  
 $\gamma - \alpha = 0.035$ ,  $\gamma - \beta = 0.019$ ,  $\beta - \alpha = 0.016$ .  
 Dispersion: Distinct,  $\rho < \nu$ .  
 $2V = 88^\circ$  ca.

Gelatinizes slowly in HCl.

**Diopside** has two equally good cleavages to which the extinction is inclined; olivine has two very unequal cleavages to which the extinction is parallel in the principal zone. Diopside does not gelatinize with HCl.

**Fayalite** has  $2V = 50^\circ$ , has higher birefringence, and is (-).

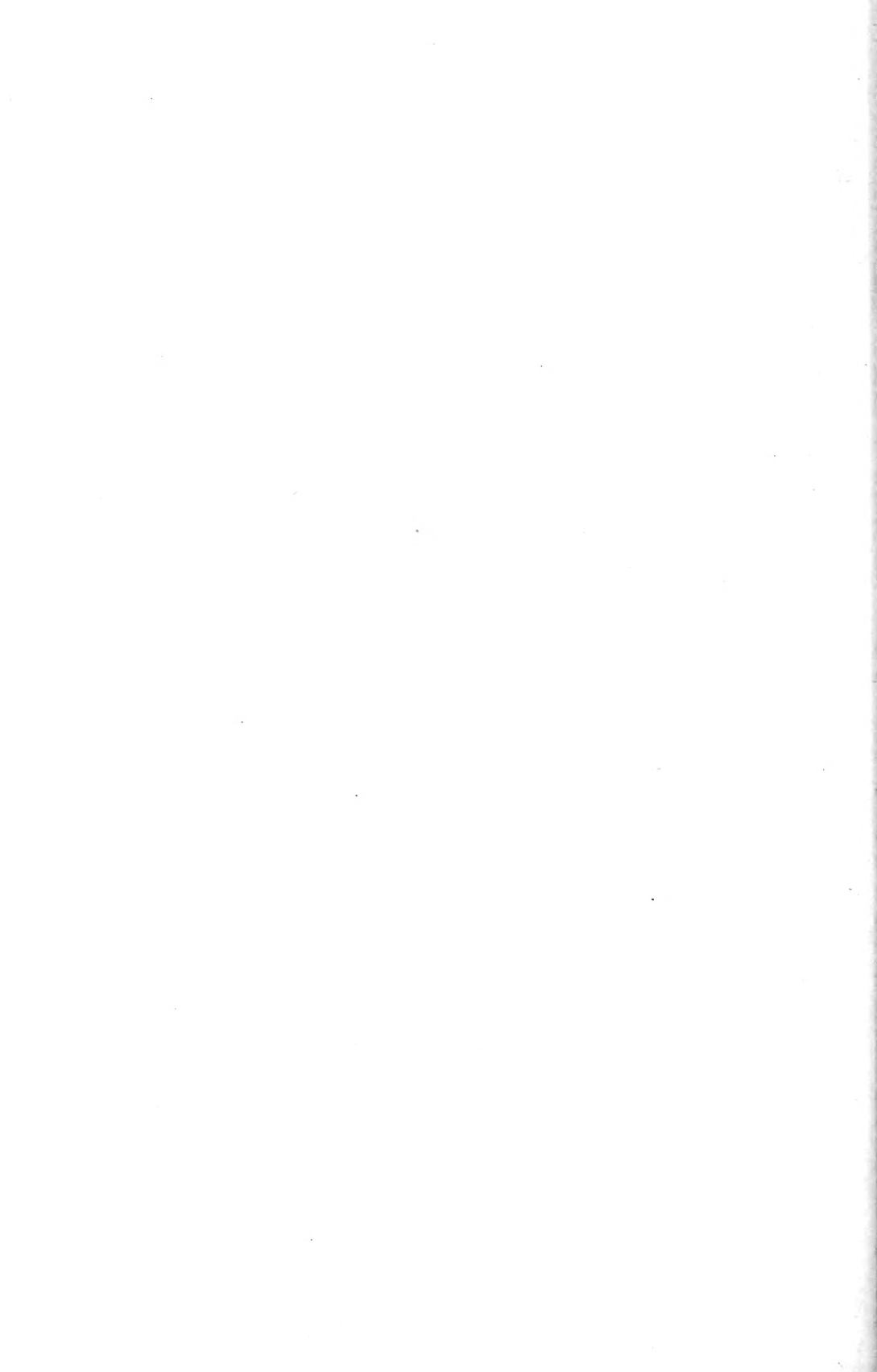
**Forsterite** has lower indices, and occurs as a contact mineral in metamorphosed limestones.

**Monticellite** is (-) and has  $2V = 37.5^\circ$ .

**Augite** and **diallage**, in sections giving parallel extinction, have different orientation of interference figures.

**Astrophyllite.**—Ti, Fe, Mn, K silicate,                      H = 3.0-4.0,                      G = 3.3-3.4.  
 Orthorhombic. (+).  
 Cleavage: (100), good.

Cut on line.





Habit: Plates, laths along  $b$ , leaves, rosettes.

Elongation: At right angles to (001), lath-shaped. ( $\pm$ ).

Orientation:  $a = \mathfrak{a}$ ,  $b = \mathfrak{c}$ .

Yellow.

Pleochroism:  $\mathfrak{a}$ =yellow to red;  $\mathfrak{b}$ =orange;  $\mathfrak{c}$ =citron-yellow.

$\alpha = 1.678$ ,  $\beta = 1.703$ ,  $\gamma = 1.733$ .

$\gamma - \alpha = 0.055$ ,  $\gamma - \beta = 0.030$ ,  $\beta - \alpha = 0.025$ .

Dispersion:  $\rho > \nu$ .

$2E = 160^\circ$  ca.

Insoluble in HCl.

Micas have smaller axial angles and lower indices.

Brittle micas have lower double refraction, smaller axial angle around the bisectrix emerging on cleavage flakes, and are ( $-$ ).

**Titanite.**— $\text{CaSiTiO}_3$ ,  $H = 5.0-5.5$ ,  $G = 3.4-3.56$ .

Monoclinic. ( $+$ ).

Cleavage: (110), distinct.  $(110):(1\bar{1}0) = 46^\circ 8'$ .

Habit: Prisms, rhombs, grains, and rods.

Orientation:  $b = \mathfrak{b}$ ,  $c: \mathfrak{c} = +39^\circ$ .

Colorless, yellowish, reddish, brownish.

Pleochroism: Weak,  $\mathfrak{c} > \mathfrak{b} > \mathfrak{a}$ .

$\alpha = 1.913$ ,  $\beta = 1.921$ ,  $\gamma = 2.054$ .

$\gamma - \alpha = 0.141$ ,  $\gamma - \beta = 0.133$ ,  $\beta - \alpha = 0.008$ .

Dispersion: Very strong,  $\rho > \nu$ .

$2E_{na} = 45^\circ-68^\circ$ .

Very slightly affected by HCl.

Monazite has lower birefringence, weak dispersion, and low extinction.

Brookite has parallel extinction,  $2V = 0^\circ-23^\circ$ , and great difference in birefringence in two directions,  $\gamma - \alpha = 0.158$ , while  $\beta - \alpha = 0.003$ .

Rutile, xenotime, hussakite, and cassiterite give no reaction for Ca.

Other minerals: The very strong double refraction and indices, and the very strong dispersion, separate titanite from other minerals.

**Brookite.**— $\text{TiO}_2$ ,  $H = 5.5-6.0$ ,  $G = 3.87-4.01$ .

Orthorhombic. ( $+$ ).

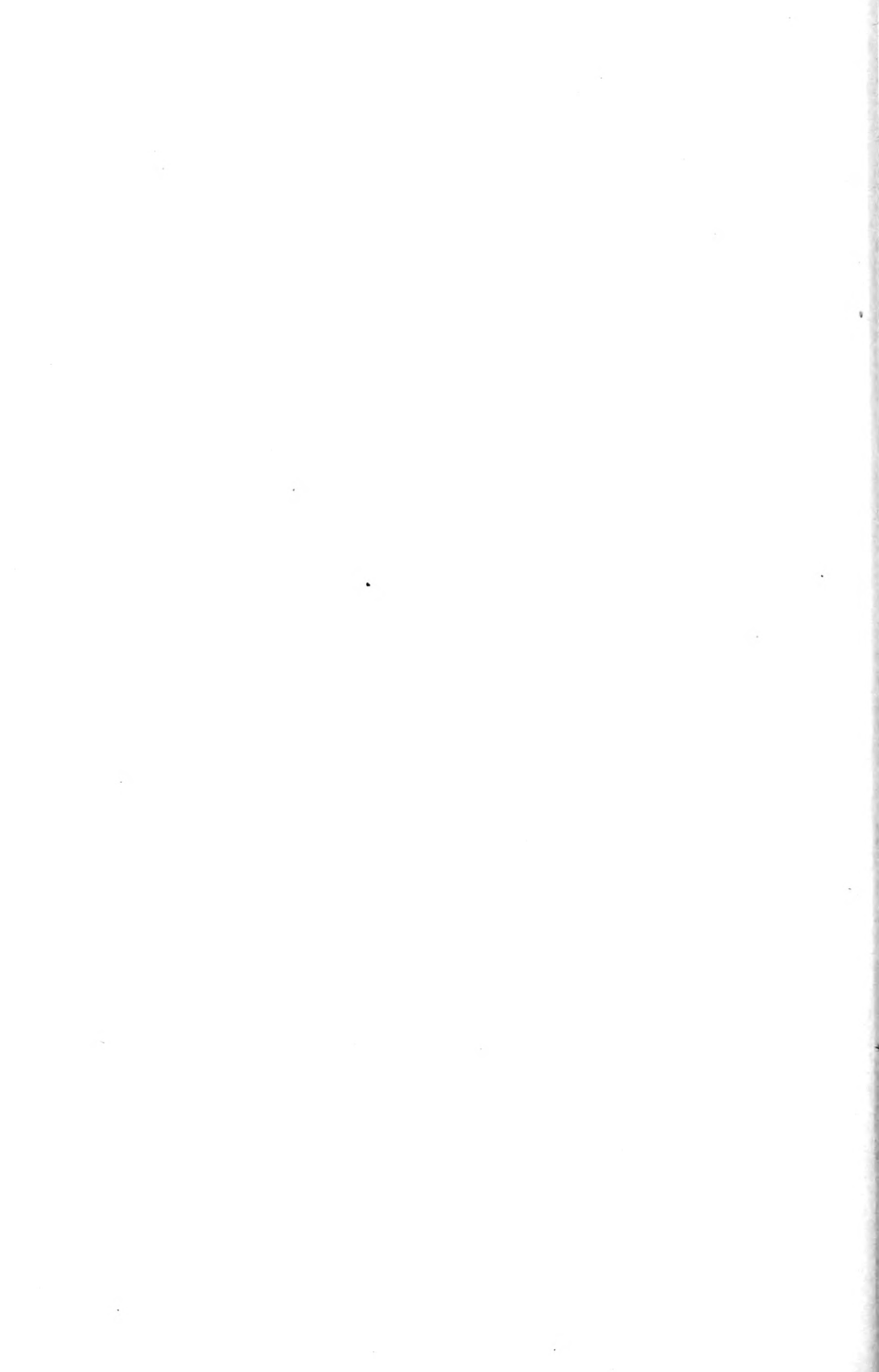
Cleavage: (010), good, though not always seen microscopically.

Habit: Tabular, plates.

Elongation: (100), narrow laths. ( $\mp$ ).

Orientation:  $a = \mathfrak{c}$ ,  $b = \mathfrak{a}$ , for red;  $a = \mathfrak{c}$ ,  $c = \mathfrak{a}$ , for green. Axial plane for red and yellow lies in (001); for green and blue, in (010).

Cut on line.



$\alpha=2.583$ ,  $\beta=2.586$ ,  $\gamma=2.741$ .

$\gamma-\alpha=0.158$ ,  $\gamma-\beta=0.156$ ,  $\beta-\alpha=0.003$ .

Dispersion:  $\rho > \nu$ .

$2V=0^\circ$  to  $23^\circ$ .

Insoluble in acids. Gives Ti reaction.

**Cassiterite** and **rutile** have different habit, and brookite has very different strength of double refraction in the (100) and (010) sections.

**Pseudobrookite.**— $\text{TiO}_2$  and  $\text{Fe}_2\text{O}_3$ ,  $H=6.0$ ,  $G=4.39-4.98$ .

Orthorhombic. (+).

Cleavage: (010), distinct.

Habit: Plates, always idiomorphic.

Elongation: (100), narrow laths. ( $\pm$ ).

Orientation:  $a = c$ ,  $b = a$ .

Fox-red, brownish.

Pleochroism: Weak,  $b > a = c$ .

$\beta = \text{high}$ .

$\gamma - \alpha = \text{high}$ .

Dispersion:  $\rho < \nu$ .

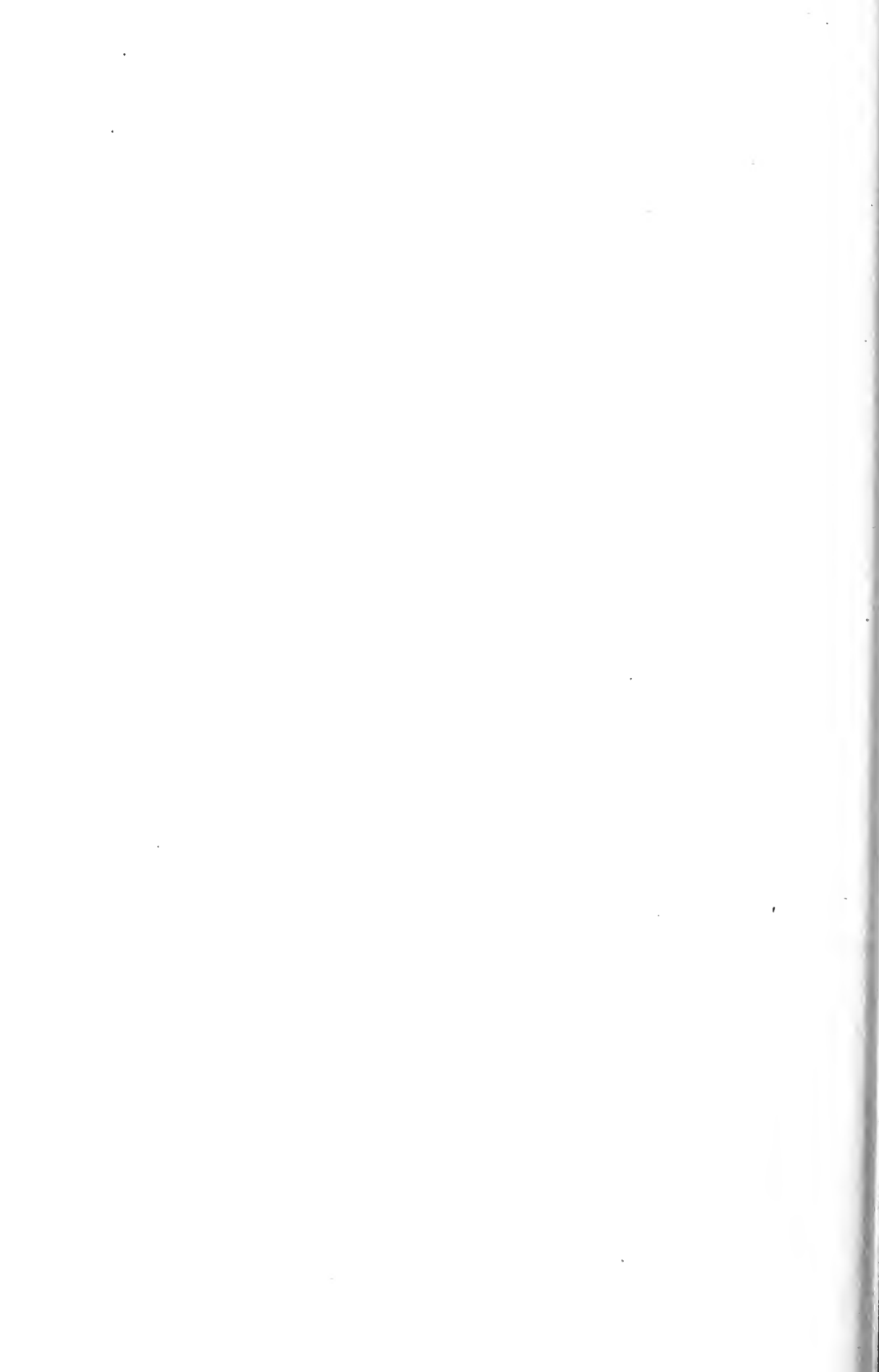
$2E=84.5^\circ$ .

Partially decomposed by boiling HCl.

**Brookite** in tablets has low double refraction;  $\beta - \alpha = 0.003$ ,

$2V$  is smaller, and  $\rho > \nu$ .

*Cut on line.*

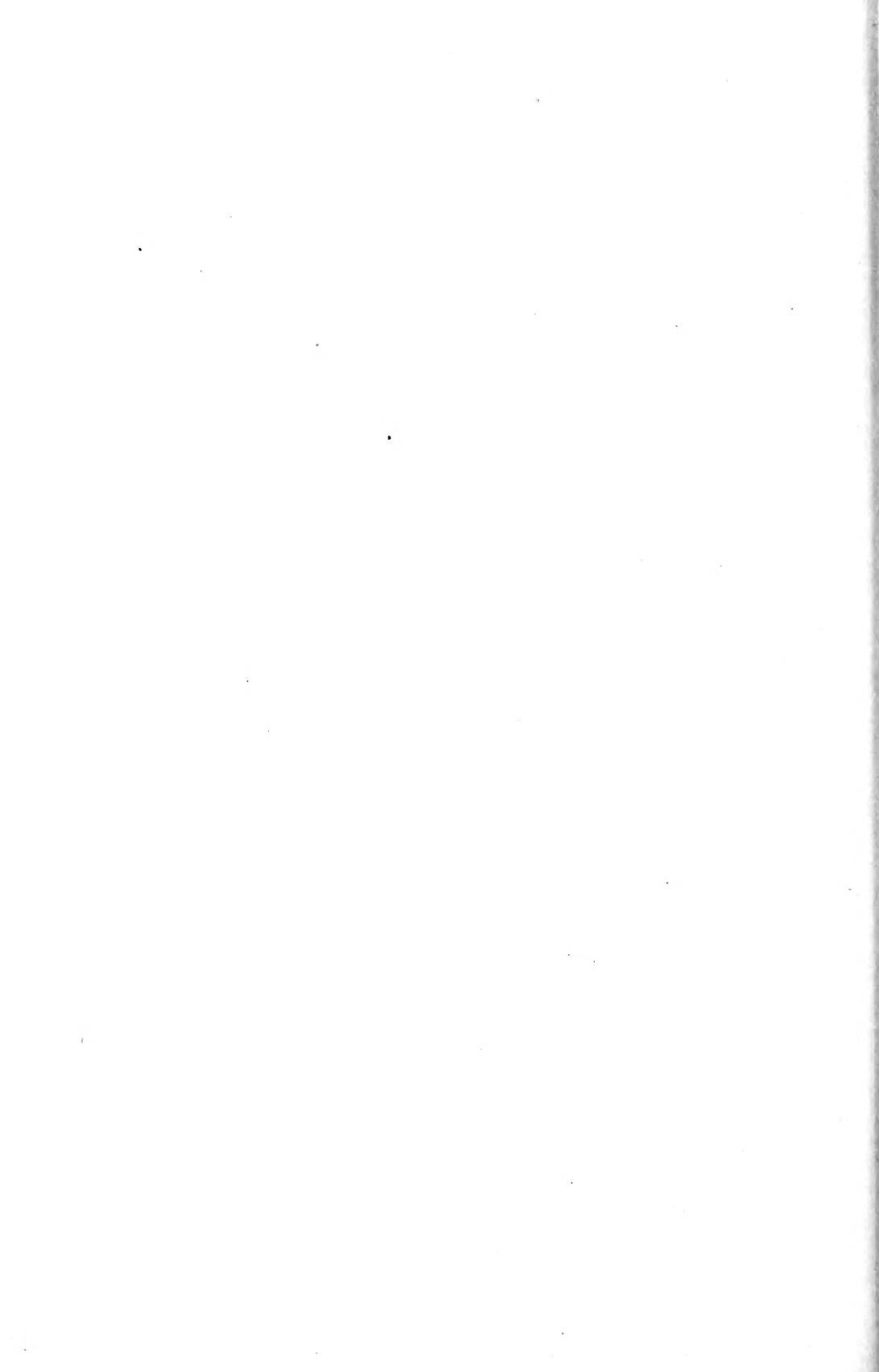


The mineral is **anisotropic**.

**Inclined** extinction.

INCLINED EXTINCTION.

*Cut on line.*



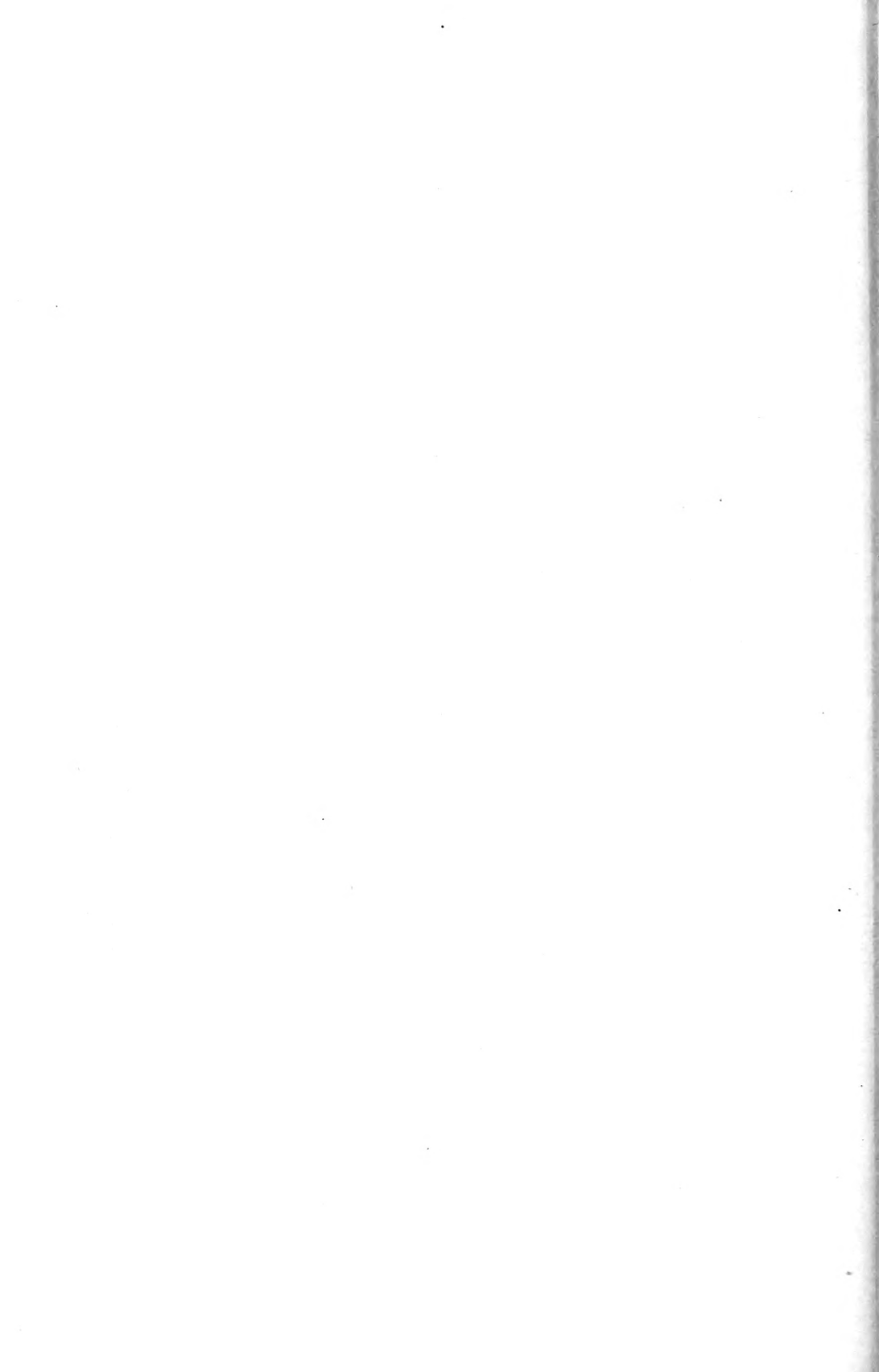
The mineral is **anisotropic**.

**Inclined extinction.**

**Colorless.**

**COLORLESS.**

*Cut on line.*





The mineral is **anisotropic**.

**Inclined** extinction.

**Colorless**.

**Index of refraction** is less than  
that of Canada balsam.

INDEX < CANADA BALSAM.

*Cut on line.*



The mineral is **anisotropic**.

**Inclined extinction**

**Colorless.**

**Index of refraction** is less than  
that of Canada balsam.

**Maximum birefringence** is less  
than that of quartz.

BIREFRINGENCE < QUARTZ.

*Cut on line.*

The Mineral is ANISOTROPIC, has INCLINED EXTINCTION, is COLORLESS, INDEX OF REFRACTION < Canada balsam, MAXIMUM BIREFRINGENCE < Quartz.										
The Mineral is NEGATIVE (-).					The Mineral is POSITIVE (+).					
← Increase in Index of Refraction. →										
1.55	1.50	1.45	1.40	1.35	In- crease in BIREFR.	1.35	1.40	1.45	1.50	1.55
The Index of Refraction is LOW.						The Index of Refraction is LOW.				
					.001					
					.002					
					.003			Phillipsite.		
					.004					
					.005			Harmotome.		
					.006					
					.007			Heulandite.		
					.008					
					.009			Oligoclase-albite.		
					.010			Gypsum.	Albite.	

**Hyalophane.**—K,Ba feldspar,  $H=6.0$ ,  $G=2.771-2.832$ .

Monoclinic. (—).

Cleavage: (001), (010), good.

Habit: Tablets, prisms, grains.

Elongation: (001):(010), laths; (110):(1 $\bar{1}$ 0), plates.

Orientation:  $b = c$ ,  $a : a = -6^\circ$ .

Colorless.

$\alpha = 1.537$ ,  $\beta = 1.540$ ,  $\gamma = 1.542$ .

$\gamma - \alpha = 0.005$ ,  $\gamma - \beta = 0.002$ ,  $\beta - \alpha = 0.003$ .

$2V = 74^\circ - 78.5^\circ$ .

Insoluble in HCl; with increase in Ba, gelatinizes.

Other feldspars, see Part II.

**Anorthoclase.**—K,Na feldspar,  $H=6.0$ ,  $G=2.56-2.61$ .

Triclinic. (—).

Cleavage: (001), (010), good. (001):(010) =  $88.5^\circ$  to  $89.5^\circ$ .

Habit: Plates, prisms, grains.

Elongation: (001):(010), laths; (110):(1 $\bar{1}$ 0), plates.

Orientation: see Part II.

Colorless.

$\alpha = 1.523$ ,  $\beta = 1.528$ ,  $\gamma = 1.529$ .

$\gamma - \alpha = 0.006$ ,  $\gamma - \beta = 0.001$ ,  $\beta - \alpha = 0.005$ .

Dispersion:  $\rho > \nu$ .

$2V = 32^\circ$  to  $53^\circ$ .

Unacted upon by acids.

Other feldspars, see Part II.

**Orthoclase.**—KAlSi<sub>3</sub>O<sub>8</sub>,  $H=6.0-6.5$ ,  $G=2.54-2.56$ .

Monoclinic. (—).

Cleavage: (001), (010), good. (001):(010) =  $90^\circ$ .

Habit: Plates, prisms, grains.

Elongation: (001):(010), laths, (—); (110):(1 $\bar{1}$ 0), plates. ( $\pm$ ).

Orientation:  $b = c$ ,  $a : a = \pm 5^\circ$  ea.

Colorless.

$\alpha = 1.519$ ,  $\beta = 1.523$ ,  $\gamma = 1.525$ .

$\gamma - \alpha = 0.006$ ,  $\gamma - \beta = 0.002$ ,  $\beta - \alpha = 0.004$ .

Dispersion: Very plain,  $\rho > \nu$ .

$2V = 70^\circ - 80^\circ$ ,  $2E_{na} = 120^\circ$  ea.

Insoluble in acids except HF.

Nephelite is uniaxial and gelatinizes with HCl.

Other feldspars, see Part II.

Soda-orthoclase has  $a : a = 10^\circ - 12^\circ$ .

**Sanidine.**—KAlSi<sub>3</sub>O<sub>8</sub>,  $H=6.0-6.5$ ,  $G=2.54-2.56$ .

Monoclinic. (—).

Cleavage: (001), (010), good.

Habit: Plates, prisms, grains. Carlsbad twins frequent.

Cut on line.



Elongation: (001):(010), laths; (110):(110), plates.  
 Orientation:  $b = c$ ,  $a : a = +5^\circ$  ca.; or  $b = b$ ,  $a : a = +5^\circ$  ca.  
 Colorless.  
 $\alpha = 1.519$ ,  $\beta = 1.523$ ,  $\gamma = 1.525$ .  
 $\gamma - \alpha = 0.006$ ,  $\gamma - \beta = 0.002$ ,  $\beta - \alpha = 0.003$ .  
 Dispersion for  $b = c$ ,  $\rho > \nu$ ; for  $b = b$ ,  $\rho < \nu$ .  
 $2V = \text{small to } 0^\circ$ .

Insoluble in acids except HF.

Nephelite is uniaxial and gelatinizes with HCl.

Other feldspars, see Part II.

**Stilbite.**— $(Na_2Ca)O \cdot Al_2O_3 \cdot 6SiO_2 + 6H_2O$ ,  $H = 3.5\text{--}4.0$ ,  $G = 2.094\text{--}2.205$ .

Monoclinic. (—).

Cleavage: (010), good.

Habit: Rods, leaves.

Elongation: (110):(110), laths. (—).

Orientation:  $b = b$ ,  $c : a = 8^\circ$  ca.

Colorless.

Pleochroism: None.

$\alpha = 1.494$ ,  $\beta = 1.498$ ,  $\gamma = 1.500$ .

$\gamma - \alpha = 0.006$ ,  $\gamma - \beta = 0.002$ ,  $\beta - \alpha = 0.004$ .

Dispersion:  $\rho < \nu$ .

$2E = 52^\circ$ .  $2V = 33^\circ$ .

Decomposed by HCl without gelatinization.

Strong Ca and Al reactions, weak Na and K.

Feldspars differ in habit.

**Oligoclase.**— $Ab_6An_1$  to  $Ab_2An_1$ ,  $H = 6.0\text{--}6.5$ ,  $G = 2.64\text{--}2.66$ .

Triclinic. (—).

Cleavage: (001), (010), good. (001):(010) =  $86^\circ 32'$ .

Habit: Plates, prisms, grains.

Elongation: (001):(010) and (110):(110).

Orientation: See Part II.

Colorless.

$\alpha = 1.540$ ,  $\beta = 1.544$ ,  $\gamma = 1.547$ .

$\gamma - \alpha = 0.007$ ,  $\gamma - \beta = 0.003$ ,  $\beta - \alpha = 0.004$ .

Dispersion:  $\rho > \nu$ .

$2V = 90^\circ\text{--}98^\circ$ .

Insoluble in hot HCl.

Other feldspars, see Part II.

**Microcline.**— $KAlSi_3O_8$ ,  $H = 6.0$ ,  $G = 2.54$ .

Triclinic. (—).

Cleavage: (001), (010), good. (001):(010) =  $89.5^\circ$ .

Habit: Plates, prisms, grains. Polysynthetic twinning.

Elongation: (001):(010), laths; (110):(110), plates.

Orientation: See Part II.

Colorless.

*Cut on line.*





$\alpha = 1.519$ ,  $\beta = 1.523$ ,  $\gamma = 1.526$ .

$\gamma - \alpha = 0.007$ ,  $\gamma - \beta = 0.003$ ,  $\beta - \alpha = 0.004$ .

Dispersion:  $\rho > \nu$ .

$2V = 71^\circ - 84^\circ$ .

Insoluble in acids, except HF.

**Orthoclase** has different extinction on (010) and (001), no microcline texture.

**Anorthoclase** has different extinction on (010) and (001), smaller axial angle and different indices.

**Other feldspars**, see Part II.

**Nephelite** has higher indices and is soluble in HCl.

**Other minerals** separated by cleavage, indices, and double refraction.

**Scolecite**.— $\text{CaAl}_2\text{Si}_3\text{O}_{10} + 3\text{H}_2\text{O}$ ,  $H = 5.0 - 5.5$ ,

$G = 2.28$ .

Monoclinic. (—).

Cleavage: (110), distinct.  $(110):(1\bar{1}0) = 88^\circ 37\frac{1}{2}'$ .

Habit: Prisms, needles.

Elongation:  $(110):(110)$ , narrow laths. (—).

Orientation:  $b = c$ ,  $c : a = 17^\circ$ .

Colorless.

Pleochroism: None.

$\beta = 1.502$ .

$\gamma - \beta = 0.007$ .

Dispersion: Strong,  $\rho < \nu$ .

$2E = 50^\circ - 60^\circ$ .  $2V = 36^\circ - 26'$ .

A zeolite.

Gelatinizes with acids and gives strong Ca and Al, and weak Na reaction.

**Feldspars** do not gelatinize and have different habit.

**Kaolin**.— $\text{H}_4\text{Al}_2\text{Si}_2\text{O}_9$ ,  $H = 2.5 - 3.0$ ,

$G = 2.6 - 2.65$ .

Monoclinic. (—).

Cleavage: (001), good.

Habit: Leaves, scales, leafy aggregates.

Elongation: At right angles to (001), lath-shaped. (+).

Orientation:  $b = c$ ,  $c : a = +13^\circ$  ca.

Colorless, yellowish, dull clouded.

Pleochroism: None.

$\beta = 1.54$  ca.

$\gamma - \alpha = 0.008$ .

$2V = 90^\circ$  more or less. Friedel found in kaolin from Miramont

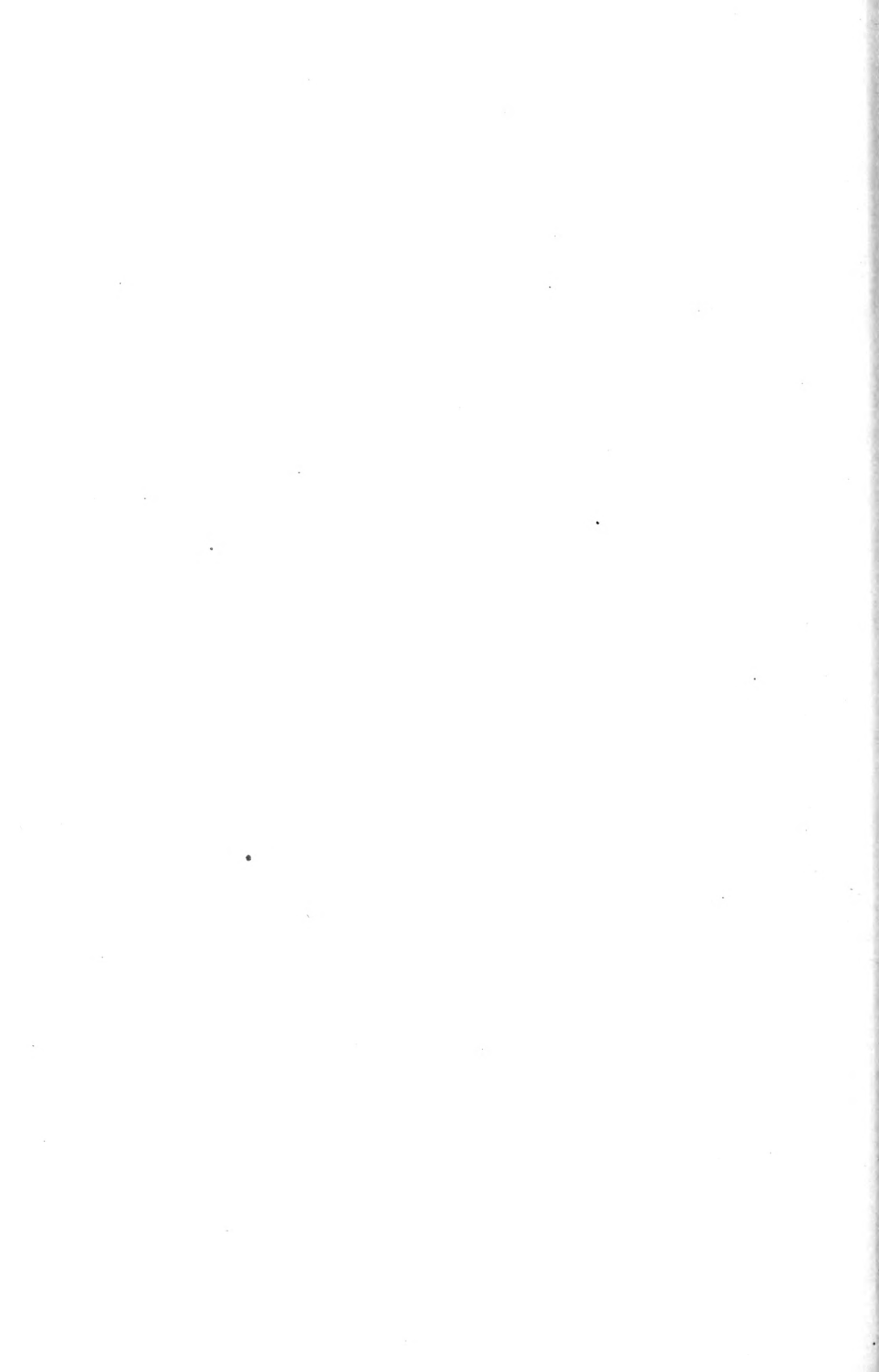
$2V$  very small to  $0^\circ$ .

Insoluble in HCl.

**Muscovite** and **hydrargillite** have higher double refraction.

Chemically separated by presence of K in muscovite and no  $\text{SiO}_2$  in hydrargillite.

*Cut on line.*



**Epistilbite.**— $\text{H}_4\text{CaAl}_2\text{Si}_6\text{O}_{18} + 3\text{H}_2\text{O}$ ,  $\text{H} = 4.0\text{--}4.5$ ,

$\text{G} = 2.25$ .

Monoclinic. (—).

Cleavage: (010), good.

Habit: Prisms, leaves.

Elongation: (110):(1 $\bar{1}$ 0), laths. (+).

Orientation:  $b = \mathbf{b}$ ,  $c: \mathbf{c} = -9^\circ$ .

Colorless.

Pleochroism: None.

$\beta = 1.51$ .

$\gamma - \alpha = 0.010$ ,  $\gamma - \beta = 0.008$ ,  $\beta - \alpha = 0.002$ .

Dispersion: Distinct,  $\rho < \nu$ .

$2E = 67^\circ\text{--}83^\circ$ .

A zeolite.

Imperfectly soluble without gelatinization in concentrated HCl. Gives strong Ca and Al reactions and weak K and Na.

**Feldspars** are insoluble in HCl, and generally have lower double refraction. Different habit.

*Cut on line.*



**Phillipsite.**— $(K_2, Ca)Al_2Si_4O_{12} + 4\frac{1}{2}H_2O$ ,  $H = 4.0-4.5$ ,  $G = 2.2$ .

Monoclinic. (+).

Cleavage: (010), (001), good.

Habit: Prisms, needles, twins, and quadruplets.

Elongation: (001):(010), lath-shaped. (+).

Orientation:  $b = a$ ,  $\alpha : \epsilon = 20^\circ-30^\circ$ .

Colorless.

Non-pleochroic.

$\beta = 1.51$  to  $1.57$ .

$\gamma - \alpha = 0.003$ .

Dispersion: Very weak.  $\rho < \nu$ .

$2E = \text{large}$ .  $2H = 84^\circ-85^\circ$ .

A zeolite.

Gelatinizes with HCl; gives strong Ca, K, and Al reactions.

**Feldspars** do not gelatinize with HCl and have different habit.

**Harmotome.**— $H_2(K_2, Ba)Al_2Si_5O_{15} + 4H_2O$ ,  $H = 4.5$ ,  $G = 2.44-2.50$ .

Monoclinic. (+).

Cleavage: (010), (001), good.

Habit: Prisms, needles.

Elongation: (001):(010), lath-shaped. ( $\pm$ ).

Orientation:  $b = \epsilon$ ,  $\alpha : a = 60^\circ$ .

Colorless.

Non-pleochroic.

$\beta = 1.516$ .

$\gamma - \alpha = 0.005$ ,  $\gamma - \beta = 0.003$ ,  $\beta - \alpha = 0.002$ .

$2H = 87^\circ 2'$ .

A zeolite.

Decomposed by HCl without gelatinization.

**Feldspars** are insoluble in HCl and have different habit.

**Heulandite.**— $H_4CaAl_2Si_6O_{18} + 3H_2O$ ,  $H = 3.5-4.0$ ,  $G = 2.18-2.22$ .

Monoclinic. (+).

Cleavage: (010), good.

Habit: Leaves, plates; usually parallel, less often rosette-like.

Elongation: (001):(100), laths, plates. (-).

Orientation:  $b = \epsilon$ ,  $\alpha : a = \text{very small}$ .

Colorless.

Non-pleochroic.

$\alpha = 1.498$ ,  $\beta = 1.499$ ,  $\gamma = 1.505$ .

$\gamma - \alpha = 0.007$ ,  $\gamma - \beta = 0.006$ ,  $\beta - \alpha = 0.001$ .

Dispersion: Distinctly crossed,  $\rho < \nu$ .

$2E = 0^\circ-55^\circ$ .

A zeolite.

Decomposed without gelatinization in HCl. Gives strong reactions for Ca and Al.

**Feldspars** have different habit and are not affected by HCl.

*Cut on line.*

1. The first part of the document is a list of names and addresses of the members of the committee.

**Oligoclase-Albite.**— $\text{Ab}_6\text{An}_4$  to  $\text{Ab}_8\text{An}_2$ ,  $H=6.0$ ,  $G=2.64$ .

Triclinic. (+).

Cleavage: (001):(010), good. (001):(010) =  $86^\circ 32'$ .

Habit: Plates, prisms, grains.

Elongation: (001):(010), laths; (110):(110), plates.

Orientation: See Part II.

Colorless.

$\alpha=1.534$ ,  $\beta=1.538$ ,  $\gamma=1.543$ .

$\gamma-\alpha=0.009$ ,  $\gamma-\beta=0.005$ ,  $\beta-\alpha=0.004$ .

Dispersion:  $\rho < \nu$ .

$2V=84^\circ-90^\circ$ .

Insoluble in HCl.

Other feldspars, see Part II.

**Gypsum.**— $\text{CaSO}_4 + 2\text{H}_2\text{O}$ ,  $H=2.0$ ,  $G=2.32$ .

Monoclinic. (+).

Cleavage: (010), ( $\bar{1}11$ ), good; (100), distinct. (110):(110) =  $68^\circ 30'$ .

Habit: Tablets, leaves, granular and fibrous aggregates.

Orientation:  $b=b$ ,  $c:c = -52^\circ$  to  $-53^\circ$ .

Colorless.

Non-pleochroic.

$\alpha=1.520$ ,  $\beta=1.523$ ,  $\gamma=1.530$ .

$\gamma-\alpha=0.010$ ,  $\gamma-\beta=0.007$ ,  $\beta-\alpha=0.003$ .

Dispersion: Distinct:  $\rho < \nu$ .

$2V=58^\circ$ .

Easily soluble in acids.

Anhydrite has higher double refraction and parallel extinction.

**Albite.**— $\text{NaAlSi}_3\text{O}_8$ ,  $H=6.0$ ,  $G=2.62$ .

Triclinic. (+).

Cleavage: (001), (010), good. (001):(010) =  $86^\circ 24'$ .

Habit: Plates, prisms, grains. Albite twinning widespread.

Elongation: (001):(010), laths; (110):(110), plates.

Orientation: See Part II.

Colorless.

Non-pleochroic.

$\alpha=1.529$ ,  $\beta=1.532$ ,  $\gamma=1.539$ .

$\gamma-\alpha=0.010$ ,  $\gamma-\beta=0.007$ ,  $\beta-\alpha=0.003$ .

Dispersion:  $\rho < \nu$ .

$2V=77^\circ-84^\circ$ .

Insoluble in HCl.

Other feldspars, see Part II.

Cut on line.





The mineral is **anisotropic**.

**Inclined extinction.**

**Colorless.**

**Index of refraction** is less than  
that of Canada balsam.

**Maximum birefringence** is greater  
than that of quartz.

BIREFRINGENCE > QUARTZ.

*Cut on line.*

The Mineral is ANISOTROPIC, has PARALLEL EXTINCTION, is COLORLESS, INDEX OF REFRACTION < Canada balsam, MAXIMUM BIREFRINGENCE > Quartz, UNIAxIAL.										
The Mineral is NEGATIVE (-).					The Mineral is POSITIVE (+).					
← Increase in Index of Refraction. →										
1.55	1.50	1.45	1.40	1.35	In-crease in BIREFR.	1.35	1.40	1.45	1.50	1.55
The Index of Refraction is LOW.						The Index of Refraction is LOW.				
					010				Gypsum. —	
									Chalcedony. —	
					015				Serpentine. •	
					020					
					025				Hydragillite. —	
					030					
					035					
					040					
					045					
					050					
					055					
					060					
					065					
					070					
					075					
					080					
					085					
					090					
					095					
					100					
					120					
					140					
					160					
					200					
					250					

**Epistilbite.**— $\text{H}_2\text{CaAl}_2\text{Si}_3\text{O}_{18} + 3\text{H}_2\text{O}$ ,  $\text{H} = 4.0\text{--}4.5$ ,  $\text{G} = 2.25$ .

Monoclinic. (—).

Cleavage: (010), good.

Habit: Prisms, leaves.

Elongation: (110):(1 $\bar{1}$ 0), laths. (+).

Orientation:  $b = \mathbf{b}$ ,  $c : \mathbf{c} = -9^\circ$ .

Colorless.

Pleochroism: None.

$\beta = 1.51$ .

$\gamma - \alpha = 0.010$ ,  $\gamma - \beta = 0.008$ ,  $\beta - \alpha = 0.002$ .

Dispersion: Distinct,  $\rho < \nu$ .

$2E = 67^\circ\text{--}83^\circ$ .

A zeolite.

Imperfectly soluble without gelatinization in concentrated HCl. Gives strong Ca and Al reactions and weak, K and Na.

**Feldspars** are insoluble in HCl and generally have lower double refraction. Different habit.

**Laumontite.**— $\text{H}_4\text{CaAl}_2\text{Si}_4\text{O}_{14} + 2\text{H}_2\text{O}$ ,  $\text{H} = 3.5\text{--}4.0$ ,  $\text{G} = 2.30$ .

Monoclinic. (—).

Cleavage: (010), good; (100), poor.

Habit: Small prisms.

Elongation: (110):(1 $\bar{1}$ 0), lath-shaped. (+).

Orientation:  $b = \mathbf{b}$ ,  $c : \mathbf{c} = +20^\circ$ .

Colorless.

Non-pleochroic.

$\alpha = 1.513$ ,  $\beta = 1.524$ ,  $\gamma = 1.525$ .

$\gamma - \alpha = 0.012$ ,  $\gamma - \beta = 0.001$ ,  $\beta - \alpha = 0.011$ .

Dispersion: Strong,  $\rho < \nu$ .

$2E = 52^\circ\ 24'$ .

Gelatinizes with HCl, strong reactions for Ca and Al and weak for Na.

**Feldspars** have different habit and do not gelatinize with HCl.

*Cut on line.*

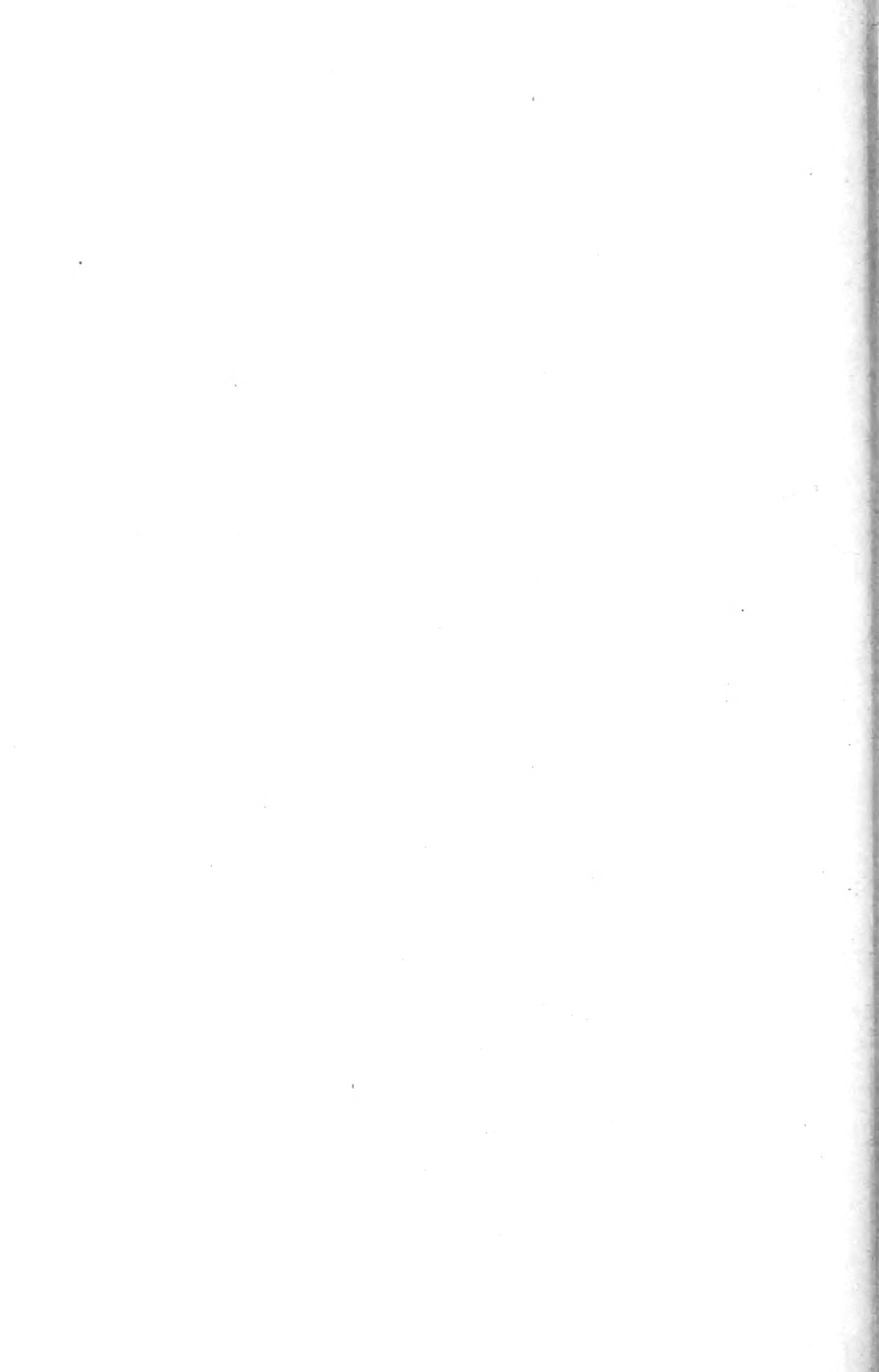


**Gypsum.**— $\text{CaSO}_4 + 2\text{H}_2\text{O}$ ,  $H = 2.0$ ,  $G = 2.32$ .  
 Monoclinic. (+).  
 Cleavage: (010), (111), good; (100), distinct.  $(110):(1\bar{1}0) = 68^\circ 30'$ .  
 Habit: Tablets, leaves, granular and fibrous aggregates.  
 Orientation:  $b = \bar{h}$ ,  $c : \bar{c} = -52^\circ$  to  $-53^\circ$ .  
 Colorless.  
 Non-pleochroic.  
 $\alpha = 1.520$ ,  $\beta = 1.523$ ,  $\gamma = 1.530$ .  
 $\gamma - \alpha = 0.010$ ,  $\gamma - \beta = 0.007$ ,  $\beta - \alpha = 0.003$ .  
 Dispersion: Distinct,  $\rho < \nu$ .  
 $2V = 58^\circ$ .  
 Easily soluble in acids.  
 Anhydrite has higher double refraction and parallel extinction.

**Chalcedony.**— $\text{SiO}_2 + \text{aq.}$ ,  $H = 6.5-7.0$ ,  $G = 2.59-2.64$ .  
 Orthorhombic. (+).  
 Cleavage: Wanting.  
 Habit: Thread-like aggregates, concretionary masses, spherulites, etc.  
 Elongation:  $(110):(1\bar{1}0)$ , thread-like. (-).  
 Orientation:  $c = a$ .  
 Colorless, yellowish, brownish.  
 Non-pleochroic.  
 $\alpha = 1.533$ ,  $\beta = 1.536$ ,  $\gamma = 1.544$ .  
 $\gamma - \alpha = 0.011$ ,  $\gamma - \beta = 0.008$ ,  $\beta - \alpha = 0.003$ .  
 $2V = 10^\circ-40^\circ$ .  
 Insoluble in HCl.  
 Zeolites do not have thread-like habit and are soluble or gelatinize with acids.  
 Quartzine and lussatite have (+) character of elongation.  
 Pseudochalcedony is (-) and  $2V$  small.

**Serpentine.**— $\text{H}_2(\text{Mg, Fe})_3\text{Si}_2\text{O}_6$ ,  $H = 3.0-4.0$ ,  $G = 2.5-2.7$ .  
 Probably orthorhombic. (+).  
 Cleavage: Generally none.  
 Habit: Threads, leaves, aggregates, massive pseudomorphs.  
 Elongation:  $(110):(1\bar{1}0)$ , thread-like. (+).  
 Orientation:  $b = a$ ,  $c = \bar{c}$ .  
 Green, yellow, colorless.  
 Pleochroism: Very feeble.  
 Index:  $n = 1.54$  ca.  
 $\gamma - \alpha = 0.013$ .  
 Dispersion:  $\rho > \nu$ .  
 $2E = 16^\circ-50^\circ$ .  
 Soluble with separation of gelatinous silica in boiling HCl or  $\text{H}_2\text{SO}_4$ .

Cut on line.



**Pennine**, when optically (-), separated by optical character; when (+), by chemical test for  $\text{Al}_2\text{O}_3$ . It has lower birefringence.

**Hydrargillite**.— $\text{Al}(\text{OH})_3$ ,  $\text{H} = 2.5\text{--}3.0$ ,  $\text{G} = 2.34\text{--}2.42$ .

Monoclinic. (+).

Cleavage: (001), good.

Habit: Small hexagonal plates, leaves.

Elongation: (001), narrow laths. (-).

Orientation:  $b = \text{h}$ ,  $c : \text{f} = +21^\circ$ .

Colorless.

Non-pleochroic.

$\alpha = \beta = 1.535$ ,  $\gamma = 1.558$ .

$\gamma - \alpha = 0.023$ .

Dispersion: Strong,  $\rho > \nu$ .

$2E = 0^\circ\text{--}40^\circ$ .

Soluble in concentrated sulphuric acid.

**Kaolin** has weaker double refraction.

**Muscovite** is (-).

**Calcite** has parallel extinction and is (-).

**Brucite** has parallel extinction and different chemical reactions.

*Cut on line.*

Volume 10, No. 1, 1968



The mineral is anisotropic.

Inclined extinction.

Colorless.

Index of refraction is greater than  
that of Canada balsam.

INDEX > CANADA BALSAM.

*Cut on line.*



The mineral is **anisotropic**.

**Inclined** extinction

**Colorless**.

**Index of refraction** is greater  
than that of Canada balsam.

**Maximum birefringence** is less  
than that of quartz.

BIREFRINGENCE < QUARTZ.

*Cut on line.*

The Mineral is ANISOTROPIC, has INCLINED EXTINCTION, is COLORLESS, INDEX OF REFRACTION > Canada balsam, MAXIMUM BIREFRINGENCE < Quartz.										
The Mineral is NEGATIVE (-).					The Mineral is POSITIVE (+).					
← Increase in Index of Refraction. →										
2.50 2.00 1.90 1.80 1.75	1.70	1.65	1.60	1.55	In-crease BIREFR.	1.55	1.60	1.65	1.70	1.75 1.80 1.90 2.00 2.50
Very H.	High.	Medium.	Not Marked.			Not Marked.	Medium.	High.		Very H.
					.001					
					.002					
					.003	Phillipsite.		Rinkite.		
					.004					
	Sapphirine.				.005					
					.006	Andesine.				
		Lepidolite.	Oligoclase.		.007					
		Bytownite.			.008	Labradorite.		Clinzoisite.		
					.009					
	Axinite.				.010					

**Sapphirine.**— $\text{Mg}_3\text{Al}_2\text{Si}_2\text{O}_{17}$ ,  $H = 7.5$ ,  $G = 3.486$ .

**Monoclinic.** (—).

**Cleavage:** Not seen in thin sections.

**Habit:** Tablets, rods, grains.

**Elongation:**  $(110):(110)$ , lath-shaped. (+).

**Orientation:**  $b = \mathbf{b}$ ,  $c: \mathbf{c} = +8^\circ$  to  $+9^\circ$ .

**Bluish, greenish, colorless.**

**Pleochroism:**  $\mathbf{a}$  = colorless,  $\mathbf{b} = \mathbf{c}$  = blue; or  $\mathbf{a}$  = light greenish blue;  $\mathbf{b}$  = dark blue-green;  $\mathbf{c}$  = yellowish green.

$\alpha = 1.706$ ,  $\beta = 1.709$ ,  $\gamma = 1.711$ .

$\gamma - \alpha = 0.005$ ,  $\gamma - \beta = 0.002$ ,  $\beta - \alpha = 0.003$ .

**Dispersion:** Distinct,  $\rho < \nu$ .

$2V = 69^\circ$ .

Insoluble in acids.

**Corundum** is uniaxial and has parallel extinction.

**Lazulite** has higher double refraction,  $\gamma - \alpha = 0.036$ .

**Cyanite, brittle micas, and blue amphibole** have distinct cleavage.

**Blue cordierite** has lower indices of refraction,  $\alpha = 1.535$ .

**Serendibite** has polysynthetic twinning.

**Lepidolite.**— $\text{Al}(\text{SiO}_4)_3\text{Al}_2\text{KLiH} + \text{Al}(\text{Si}_3\text{O}_8)_3\text{K}_3\text{Li}_3(\text{AlF}_2)_3$ ,  $H = 2.5-4.0$ ,  $G = 2.8-2.9$ .

**Monoclinic.** (—).

**Cleavage:**  $(001)$ , good.

**Habit:** Leaves, leafy aggregates.

**Elongation:** At right angles to  $(001)$ , lath-shaped. (+).

**Orientation:**  $b = \mathbf{c}$ ,  $c: \mathbf{a} = +0^\circ$  to  $+2^\circ$ ; or rarely  $b = \mathbf{b}$ ,  $c: \mathbf{a} = 0^\circ$  to  $+2^\circ$ .

**Colorless, reddish.**

**Pleochroism:** Weak or none.

$\alpha = ( )$ ,  $\beta = 1.598$ ,  $\gamma = 1.605$ .

$\gamma - \beta = 0.007$ .

**Dispersion:** Weak,  $\rho \geq \nu$ .

$2E = 32^\circ-84^\circ$ .

Insoluble in acids.

**Muscovite and paragonite** do not give Li flame. See also Part II.

**Oligoclase.**— $\text{Ab}_6\text{An}_1\text{—Ab}_2\text{An}_1$ ,  $H = 6.0-6.5$ ,  $G = 2.64-2.66$ .

**Triclinic.** (—).

**Cleavage:**  $(001)$ ,  $(010)$ , good.  $(001):(010) = 86^\circ 32'$ .

**Habit:** Plates, prisms, grains.

**Elongation:**  $(001):(010)$ ,  $(110):(1\bar{1}0)$ .

**Orientation:** See Part II.

**Colorless.**

*Cut on line.*



$\alpha = 1.540$ ,  $\beta = 1.544$ ,  $\gamma = 1.547$ .  
 $\gamma - \alpha = 0.007$ ,  $\gamma - \beta = 0.003$ ,  $\beta - \alpha = 0.004$ .  
 Dispersion:  $\rho > \nu$ .  
 $2V = 90^\circ - 98^\circ$ .

Insoluble in hot HCl.

**Other feldspars**, see Part II.

**Bytownite.**— $\text{Ab}_1\text{An}_3$  to  $\text{Ab}_1\text{An}_6$ ,  $H = 6.0$ ,  $G = 2.71 - 2.74$ .

Triclinic. (—).

Cleavage: (001), (010), good.

Habit: Plates, prisms, grains.

Elongation: (001):(010), laths; (110):(110), plates.

Orientation: See Part II.

Colorless.

$\alpha = 1.561$ ,  $\beta = 1.564$ ,  $\gamma = 1.569$ .

$\gamma - \alpha = 0.008$ ,  $\gamma - \beta = 0.005$ ,  $\beta - \alpha = 0.003$ .

Dispersion:  $\rho > \nu$ .

$2V = 76^\circ - 80^\circ$ .

Decomposed by HCl with separation of gelatinous silica.

**Other feldspars**, see Part II.

**Axinite.**— $\text{Ca}_7\text{Al}_4\text{B}_2(\text{SiO}_4)_8$ ,  $H = 6.5 - 7.0$ ,  $G = 3.27 - 3.29$ .

Triclinic. (—).

Cleavage: (010), distinct.

Habit: Grains, tablets.

Orientation: Plane of the optic axes makes an angle of  $24^\circ 40'$  with the edge (111):(111), and of  $40^\circ$  with (111):(110).

Colorless, yellowish, brownish, violet.

Pleochroism: In thin sections weak or not noticeable.

$\alpha = 1.685$ ,  $\beta = 1.692$ ,  $\gamma = 1.695$ .

$\gamma - \alpha = 0.010$ ,  $\gamma - \beta = 0.003$ ,  $\beta - \alpha = 0.007$ .

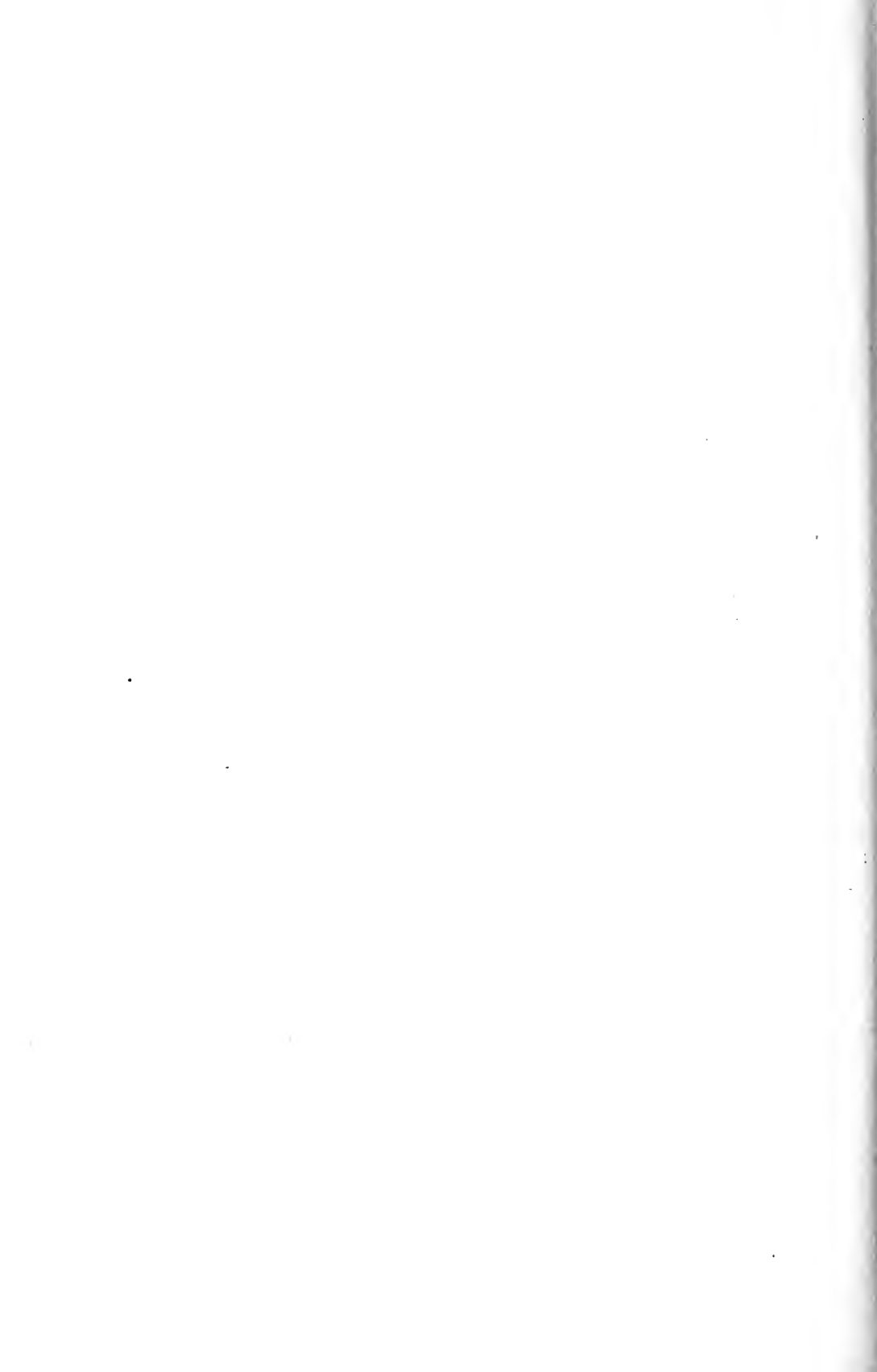
Dispersion: Distinct,  $\rho < \nu$ .

$2E$  large and variable,  $158^\circ 13'$  to  $165^\circ 38'$ .  $2V = 71^\circ 38'$  to  $71^\circ 49'$ .

But slightly affected by acids; after fusion gelatinizes with HCl.

**Other minerals:** Axinite is separated by the characteristic occurrence of acute-angled edges, by the combination of strong indices with weak double refraction and good cleavage. Chemically by the presence of B.

*Cut on line.*





**Phillipsite.**— $(K_2Ca)Al_2Si_4O_{12} + 4\frac{1}{2}H_2O$ ,  $H = 4.0-4.5$ ,  $G = 2.2$ .

Monoclinic. (+).

Cleavage: (010), (001), good.

Habit: Prisms, needles, twins, and quadruplets.

Elongation: (001):(010), lath-shaped. (+).

Orientation:  $b = a$ ,  $a : c = 20^\circ-30^\circ$ .

Colorless.

Non-pleochroic.

$\beta = 1.51$  to  $1.57$ .

$\gamma - \alpha = 0.003$ .

Dispersion: Very weak,  $\rho < \nu$ .

$2E = \text{large}$ .  $2H = 84^\circ-85^\circ$ .

A zeolite.

Gelatinizes with HCl; gives strong Ca, K, and Al reactions.

**Feldspars** do not gelatinize with HCl and have different habit.

**Rinkite.**— An iron-bearing titanosilicate of Ca, Ce, and Na,  $H = 5.0$ ,  $G = 3.46-3.50$ .

Monoclinic. (+).

Cleavage: (100), good.

Habit: Tablets, (100). Twinning (100) frequent.

Elongation: (100):(010), lath-shaped. ( $\mp$ ).

Orientation:  $b = a$ ,  $c : b = 7^\circ$  ca.

Yellowish, colorless.

Pleochroism:  $r > b > a$ .

$\alpha = 1.665$ ,  $\beta = 1.668$ ,  $\gamma = ( )$ .

$\beta - \alpha = 0.003$ .

Dispersion: Strong,  $\rho < \nu$ .

$2E = 78^\circ-82.5^\circ$ .

Easily soluble in HCl with separation of  $SiO_2$ .

**Mosandrite** has  $b = b$ ;  $c : a = 3^\circ$ ; also strong  $\rho > \nu$ .

**Andesine.**— $Ab_3An_2$  to  $Ab_4An_4$ ,  $H = 6.0$ ,  $G = 2.66-2.69$ .

Triclinic. (+).

Cleavage: (001):(010), good. (001):(010) =  $86^\circ 14'$ .

Habit: Plates, prisms, grains.

Elongation: (001):(010), laths; (110):(110), plates.

Orientation: See Part II.

Colorless.

$\alpha = 1.549$ ,  $\beta = 1.553$ ,  $\gamma = 1.555$ .

$\gamma - \alpha = 0.006$ ,  $\gamma - \beta = 0.002$ ,  $\beta - \alpha = 0.004$ .

Dispersion:  $\rho < \nu$ .

$2V = 80^\circ-90^\circ$ .

Insoluble in HCl.

**Other feldspars**, see Part II.

*Cut on line.*



**Labradorite.**— $\text{Ab}_1\text{An}_1$  to  $\text{Ab}_1\text{An}_2$ ,  $\text{H}=6.0$ ,  $\text{G}=2.69-2.71$ .

Triclinic. (+).

Cleavage: (001), (010), good. (001):(010)= $86^\circ 12'$ .

Habit: Plates, prisms, grains.

Elongation: (001):(010), laths; (110):(110), plates.

Orientation: See Part II.

Colorless.

$\alpha=1.555$ ,  $\beta=1.558$ ,  $\gamma=1.563$ .

$\gamma-\alpha=0.008$ ,  $\gamma-\beta=0.005$ ,  $\beta-\alpha=0.003$ .

Dispersion:  $\rho < \nu$ .

$2V=75^\circ-80^\circ$ .

Decomposed by HCl with separation of silica.

Other feldspars, see Part II.

**Clinzoisite.**— $\text{Al}(\text{SiO}_4)_3(\text{Al,Fe})_2\text{Ca}\cdot\text{CaOH}$ ,  $\text{H}=6.5$ ,  $\text{G}=3.3-3.5$ .

Monoclinic. (+).

Cleavage: (001), good; (100), distinct. (001):(100)= $64^\circ 37'$ .

Habit: Prisms and rods elongated on  $b$ , grains. Twinning (100).

Elongation: (001):(100), lath-shaped. ( $\pm$ ).

Orientation:  $b=\mathbf{b}$ ,  $c:\mathbf{a}=-3^\circ$ .

Colorless, reddish.

Pleochroism: Weak.

$\alpha=1.716$ ,  $\beta=1.718$ ,  $\gamma=1.724$ .

$\gamma-\alpha=0.008$ ,  $\gamma-\beta=0.006$ ,  $\beta-\alpha=0.002$ .

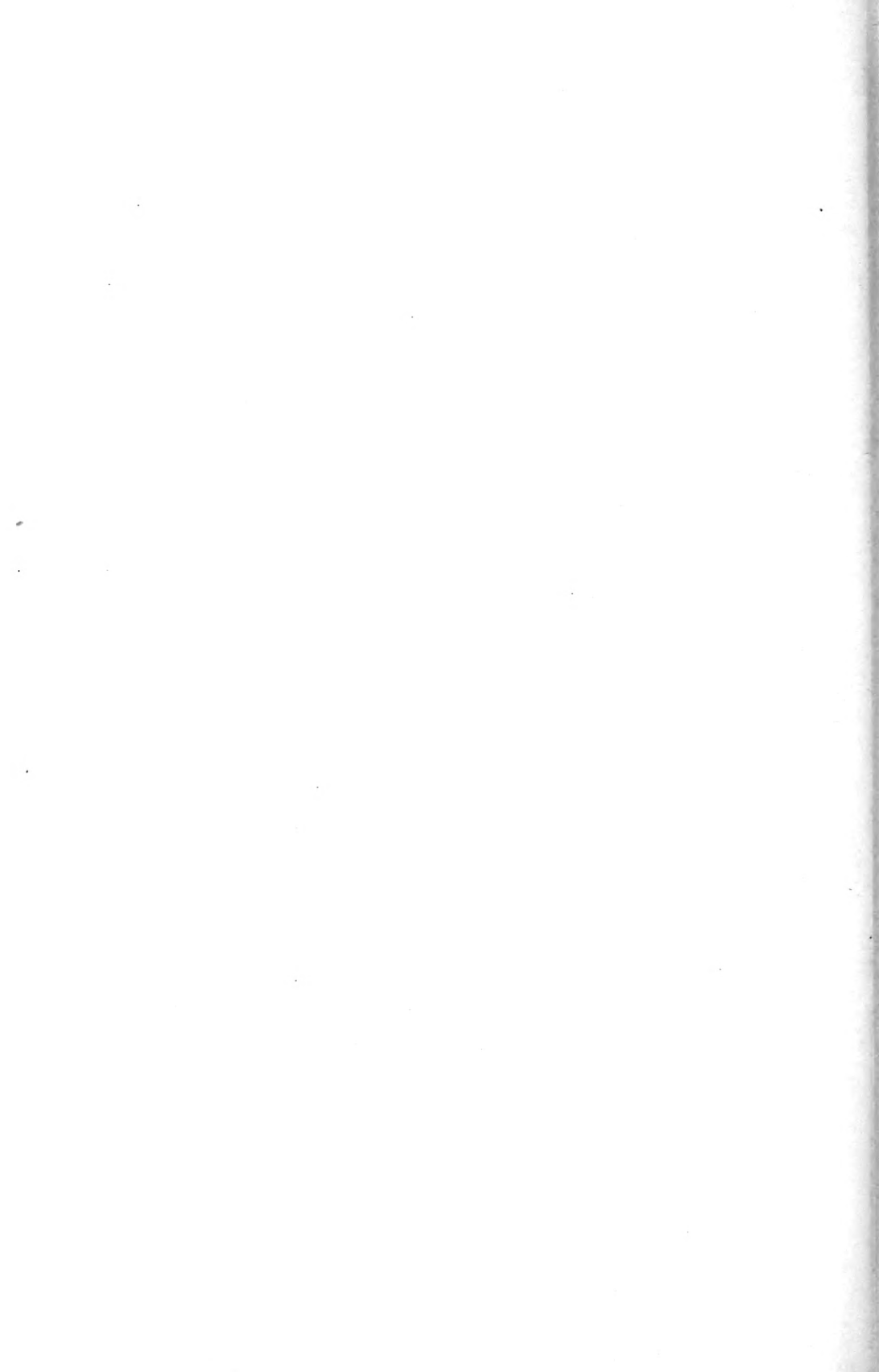
Dispersion: Strong,  $\rho < \nu$ .

$2V=80^\circ-90^\circ$ .

An iron-poor or iron-free epidote. Pistacite is the iron-rich epidote.

Abnormal interference colors common. Strong dispersion of the bisectrices. Insoluble in HCl.

Zoisite has parallel extinction and smaller value for  $2V$ .



The mineral is **anisotropic**.

**Inclined extinction.**

**Colorless.**

**Index of refraction** is greater than  
that of Canada balsam.

**Maximum birefringence** is greater  
than that of quartz.

BIREFRINGENCE > QUARTZ.

*Cut on line.*

The Mineral is ANISOTROPIC, has INCLINED EXTINCTION, is COLORLESS, INDEX OF REFRACTION > Canada balsam, MAXIMUM BIREFRINGENCE > Quartz.									
The Mineral is NEGATIVE (—).					The Mineral is POSITIVE (+).				
Increase in Index of Refraction. —————>									
2.50 2.00 1.90 1.80 1.75	1.70	1.65	1.60	1.55	In- creasing BIREFR.	1.55	1.60	1.65	1.70
Very H.	High.	Medium.	Not Marked.			Not Marked.	Medium.	High.	Very H.
	Axinite. —				.010	Celsian. —			Ottrelite. —
	Disthene. —	Antigorite. — Anorthite. —				Mosandrite. —	Johnstrupite.		
		Wollastonite. —			.015			Spodumene. —	
		Carpholite. •			.020				
		Rosenbuschite. + Actinolite. —	Tremolite. —		.025			Augite. —	
					.030	Jadeite. •	Diopside. Diallage. —		
Pistacite. —	Piedmontite. —					Mn. Piedmontite. —			
		Lazulite. — Muscovite. — Paragonite. —			.035		Olivine. —		
					.040	Pectolite. •			
	Datolite. —		Phlogopite. —		.045			Monazite. —	
					.050				
Grünerite. •					.055				
					.060				
					.065				
					.070				
					.075				
					.080				
					.085				
					.090				
					.095				
					.100				
					.120				
					.140				
					.160				Titanite. —
					.200				
					.250				

**Axinite.**— $\text{Ca}_7\text{Al}_4\text{B}_2(\text{SiO}_4)_8$ ,  $\text{H}=6.5-7.0$ ,  $\text{G}=3.27-3.29$ .  
 Triclinic. (—).  
 Cleavage: (010), distinct.  
 Habit: Grains, tablets.  
 Orientation: Plane of the optic axes makes an angle of  $24^\circ 40'$  with the edge (111):(111), and of  $40^\circ$  with (111):(110).  
 Colorless, yellowish, brownish, violet.  
 Pleochroism: In thin sections weak or not noticeable.  
 $\alpha=1.685$ ,  $\beta=1.692$ ,  $\gamma=1.695$ .  
 $\gamma-\alpha=0.010$ ,  $\gamma-\beta=0.003$ ,  $\beta-\alpha=0.007$ .  
 Dispersion: Distinct,  $\rho < \nu$ .  
 $2E$  large and variable;  $158^\circ 13'$  to  $165^\circ 38'$ .  $2V=71^\circ 38'$  to  $71^\circ \pm 9'$ .

But slightly affected by acids; after fusion gelatinizes with HCl.

**Other minerals:** Axinite is separated by its characteristic occurrence with acute-angled edges, by the combination of strong indices with weak double refraction and good cleavage. Chemically by the presence of B.

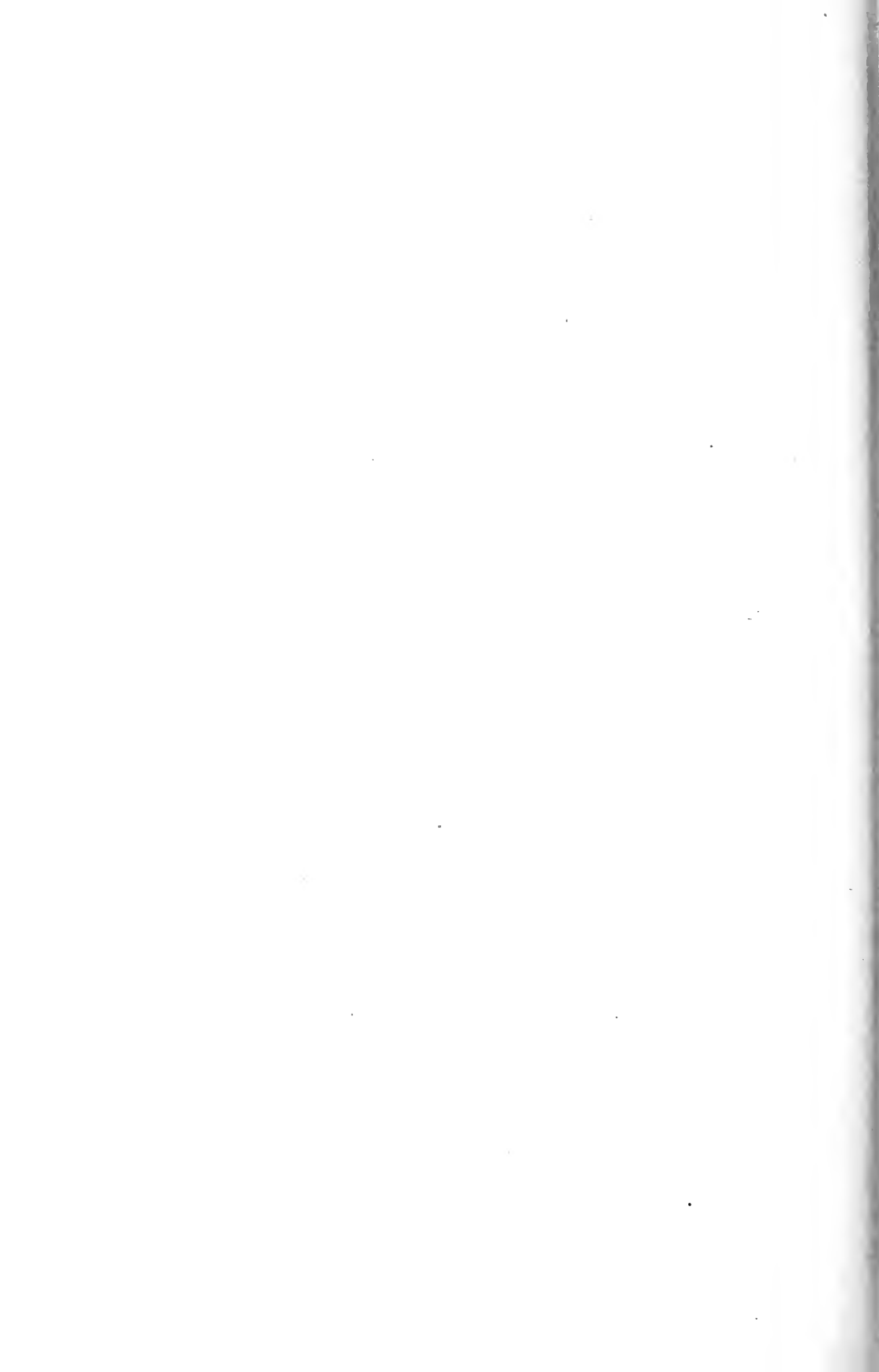
**Antigorite.**— $\text{H}_4(\text{Mg}, \text{Fe})_3\text{Si}_2\text{O}_9$ ,  $\text{H}=2.5$ ,  $\text{G}=2.622$ .  
 Orthorhombic. (—).  
 Habit: Lamellæ, leaves, scales.  
 Elongation: At right angles to (100), lath-shaped. (+).  
 Orientation:  $a=a$ ,  $b=c$ .  
 Greenish, colorless, yellowish.  
 Non-pleochroic.  
 $\alpha=1.560$ ,  $\beta=1.570$ ,  $\gamma=1.571$ .  
 $\gamma-\alpha=0.011$ ,  $\gamma-\beta=0.001$ ,  $\beta-\alpha=0.010$ .  
 Dispersion:  $\rho > \nu$ .  
 $2E=16^\circ-98^\circ$ .

In boiling HCl silica separates.

**Pennine** is pleochroic, the double refraction is lower, and the indices are higher.

**Ordinary serpentine** is (+).

**Disthene.**— $\text{Al}_2\text{SiO}_5$ ,  $\text{H}=4.0-7.0$ ,  $\text{G}=3.56-3.67$ .  
 Triclinic. (—).  
 Cleavage: (100) good, (010), distinct; (100):(010)= $74^\circ$ .  
 Habit: Prisms, tablets.  
 Elongation: (100):(010), lath-shaped. (+).  
 Orientation:  $a$ =nearly at right angles to (100),  $c$ =inclined  $30^\circ$  on (100) against edge (100):(010).  
 Colorless, blue.  
 Pleochroism: Weak, between blue and colorless.  
 $\alpha=1.717$ ,  $\beta=1.722$ ,  $\gamma=1.729$ .  
 $\gamma-\alpha=0.012$ ,  $\gamma-\beta=0.007$ ,  $\beta-\alpha=0.005$ .





Dispersion:  $\rho > \nu$ ,  $2V = 82^\circ$ .

Insoluble in acids.

Does not occur in eruptive rocks, but in crystalline schists and gneisses.

**Sillimanite** and **andalusite** are orthorhombic, have parallel extinction, and different cleavage.

**Sillimanite** has higher double refraction and smaller  $2V$  ( $31^\circ$  to  $42^\circ$ ).

**Topaz** has basal cleavage, and is orthorhombic.

**Zoisite** and **colorless epidote** have different position of axial plane in relation to cleavage.

**Serendibite** and **dumortierite** have different pleochroism.

**Blue amphibole** has different cleavage and lower indices of refraction.

**Anorthite.**— $\text{CaAl}_2\text{Si}_2\text{O}_8$ ,  $H = 6.0$ ,  $G = 2.74-2.76$ .

Triclinic. (—).

Cleavage: (001), (010), good.

Habit: Plates, prisms, grains.

Elongation: (001):(010), laths; (110):(1 $\bar{1}$ 0), plates.

Orientation: See Part II.

Colorless.

$\alpha = 1.575$ ,  $\beta = 1.584$ ,  $\gamma = 1.588$ .

$\gamma - \alpha = 0.013$ ,  $\gamma - \beta = 0.004$ ,  $\beta - \alpha = 0.009$ .

Dispersion:  $\rho > \nu$ .

$2V = 77^\circ-80^\circ$ .

Decomposed by HCl with separation of gelatinous silica.

Other feldspars, see Part II.

**Wollastonite.**— $\text{CaSi}_3\text{O}_6$ ,  $H = 4.5-5.0$ ,  $G = 2.8-2.9$ .

Monoclinic. (—).

Cleavage: (100), good; (001), distinct. (100):(001) =  $84.5^\circ$ .

Habit: Tablets rods along  $b$ . Twinning on (100).

Elongation: (001):(100), lath-shaped to tabular. ( $\pm$ ).

Orientation:  $b = \mathbf{b}$ ,  $c : a = +32^\circ 12'$ .

Colorless.

Pleochroism: None.

$\alpha = 1.619$ ,  $\beta = 1.632$ ,  $\gamma = 1.634$ .

$\gamma - \alpha = 0.015$ ,  $\gamma - \beta = 0.002$ ,  $\beta - \alpha = 0.013$ .

Dispersion: Distinct,  $\rho > \nu$ .

$2V = 40^\circ$  to  $69^\circ$

Gelatinizes with HCl.

**Pectolite** and **tremolite** differ in not having the plane of the optic axes at right angles to the elongation, which is very characteristic of sections in the ortho-diagonal zone of wollastonite.

**Epidote**, when colorless, is separated by not gelatinizing with acids, higher indices, and higher double refraction.

Cut on line.



**Carpholite.**— $\text{H}_4\text{MnAl}_2\text{Si}_4\text{O}_{10}$ ,  $H=5.0-5.5$ ,  $G=2.935$ .

Monoclinic. (—).

Cleavage: Unnoticeable.

Habit: Rods, fibres.

Elongation:  $(110):(1\bar{1}0)$ , narrow laths. (+).

Orientation:  $b=a$ ,  $c:t=4^\circ$  ca.

Colorless, greenish yellow.

Pleochroism: Distinct,  $\epsilon$ =colorless,  $a=b$ =yellowish green.

Index:  $n=1.627$

$\gamma-\alpha=0.022$ .

$2V=60^\circ$ .

Insoluble in acids.

**Rosenbuschite** is soluble in acids, elongation (—).

$2V=90^\circ$ , cleavage (001), good.

**Sillimanite** is (+), non-pleochroic, good (100) cleavage.

**Rosenbuschite.**— $2\text{Na}_2\text{ZrO}_2\cdot\text{F}_2\cdot 6\text{CaSiO}_3\cdot\text{TiSiO}_3\cdot\text{TiO}_2$ ,  $H=5.0-6.0$ ,  $G=3.30-3.315$ .

Monoclinic. ( $\pm$ ).

Cleavage: (001), good; (100), distinct.  $(001):(100)=78^\circ$ .

Habit: Rods along  $b$ .

Elongation: Narrow laths. (—).

Orientation:  $i=a$ ,  $c:t=+13^\circ$ .

Colorless, light greenish yellow.

Pleochroism: Not marked,  $\epsilon>b>a$ .

Index:  $n=1.65$  ca.

$\gamma-\alpha=0.026$  ca.

$2V=\text{near } 90^\circ$ .

Easily attacked by HCl.

**Sillimanite** and **carpholite** are not affected by HCl and have (+) elongation.

**Wollastonite** has ( $\pm$ ) elongation, lower double refraction, and higher extinction angle.

**Pectolite** has (+) elongation.

**Tremolite.**— $\text{CaMg}_3\text{Si}_4\text{O}_{12}$ ,  $H=5.0-6.0$ ,  $G=2.9-3.1$ .

Monoclinic. (—).

Cleavage: (110), good; (100), distinct; (010), poor.  $(110):(110)=55^\circ 49'$ .

Habit: Rods, leaves, grains. (100) twinning occurs.

Elongation:  $(110):(110)$ , lath-shaped. (+).

Orientation:  $b=b$ ,  $c:t=-16^\circ$ .

Colorless.

Non-pleochroic.

$\alpha=1.604$ ,  $\beta=1.618$ ,  $\gamma=1.630$ .

$\gamma-\alpha=0.026$ ,  $\gamma-\beta=0.012$ ,  $\beta-\alpha=0.014$ .

Dispersion: Weak,  $\rho<\nu$ .

$2V=81^\circ$  to  $87.5^\circ$ .



Hardly affected by HCl.

**Wollastonite** gelatinizes with HCl and has trace of the plane of the optic axes at right angles to the cleavage, elongation ( $\pm$ ).

**Pyroxenes**, see Part II.

**Actinolite** is pale green and pleochroic.

**Actinolite**.— $(\text{FeMg})_4\text{Si}_4\text{O}_{12}$ ,  $H=5.0-6.0$ ,  $G=3.0-3.2$ .  
Monoclinic. (—).

Cleavage: (110), good; (100), distinct; (010), poor.  $(110):(1\bar{1}0)=55^\circ 49'$ .

Habit: Rods, leaves, grains. (100) twinning occurs.

Elongation:  $(110):(1\bar{1}0)$ , lath-shaped. (+).

Orientation:  $b=\bar{b}$ ,  $c:\epsilon=-15^\circ$ .

Green.

Pleochroism: Hardly noticeable in thin sections.  $\epsilon$ =green;  $\bar{b}$  and  $a$ =yellowish green.

$\alpha=1.607$ ,  $\beta=1.624$ ,  $\gamma=1.634$ .

$\gamma-\alpha=0.027$ ,  $\gamma-\beta=0.010$ ,  $\beta-\alpha=0.017$ .

Dispersion: Weak,  $\rho < \nu$ .

$2V=80^\circ$  to  $81.5^\circ$ .

But slightly acted upon by HCl.

**Pistacite** has trace of the plane of the optic axes at right angles to the cleavage, and ( $\pm$ ) elongation.

**Pyroxenes** differ in cleavage and have higher extinction angles. See Part II.

**Pistacite**.— $(\text{Epidote})$ ,  $\text{Al}(\text{SiO}_4)_3(\text{Al}, \text{Fe})_2\text{Ca}\cdot\text{CaOH}$ ,  $H=6.5$ ,  $G=3.3-3.5$ .  
Monoclinic. (—).

Cleavage: (001), good; (100), distinct.  $(001):(100)=64^\circ 37'$ .

Habit: Prisms, rods elongated along  $b$ , grains. Twinning (100) occurs.

Elongation:  $(001):(100)$ , lath-shaped. ( $\pm$ ).

Orientation:  $b=\bar{b}$ ,  $c:a=+3^\circ$ .

Green, yellow, brownish, colorless.

Pleochroism:  $a$ =colorless to yellowish or greenish;  $\bar{b}$ =yellowish to yellowish gray, lavender;  $\epsilon$ =green, light yellowish brown.

$\alpha=1.714$ ,  $\beta=1.741$ ,  $\gamma=1.746$ .

$\gamma-\alpha=0.032$ ,  $\gamma-\beta=0.005$ ,  $\beta-\alpha=0.027$ .

Dispersion:  $\rho > \nu$ .

$2V=74^\circ-90^\circ$ .

Not affected by HCl.

Pistacite is the Fe-rich epidote; clinozoisite the Fe-poor or free epidote.

**Pyroxene** has (110) cleavage; in sections parallel to the long direction the trace of the optic axes is parallel to the cleavage; in epidote at right angles to it.

**Clinozoisite** has lower double refraction, is ( $\pm$ ), and has strong  $\rho < \nu$  dispersion.

Cut on line.



**Piedmontite.**— $\text{Al}(\text{SiO}_4)_3(\text{Al}, \text{Mn}, \text{Fe})_2\text{Ca} \cdot \text{CaOH}$ ,  $H=6.5$ ,  $G=3.40$ .

Monoclinic. (—). Mn-rich piedmontite is (+).

Cleavage: (001), good; (100), distinct.  $(001):(101)=63^\circ 30.5'$ .

Habit: Prisms, rods elongated along  $b$ , grains.

Elongation:  $(001):(100)$ , lath-shaped. ( $\pm$ ).

Orientation:  $b=\mathfrak{b}$ ,  $c:\mathfrak{a}=+5^\circ$  to  $+6^\circ$ .

Red, yellow, colorless.

Pleochroism: Strong and characteristic.  $\mathfrak{a}$ =orange;  $\mathfrak{b}$ =violet, amethyst;  $\mathfrak{c}$ =red.

Indices: Similar to pistacite.

Birefringence: Similar to pistacite.

$2V=90^\circ$ ; it becomes greater than  $90^\circ$  in the Mn-rich piedmontites, and the mineral becomes optically (+).

A manganese epidote.

Insoluble in HCl.

Pistacite, clinozoisite, and orthite have different pleochroism.

Other minerals are separated by the epidote-like character of piedmontite and by the pleochroism.

**Lizulite.**— $(\text{AlOH})_2\text{Mg}(\text{PO}_4)_2$ ,  $H=5.0-6.0$ ,  $G=3.00-3.12$ .

Monoclinic. (—).

Cleavage: Seldom seen microscopically.

Habit: Pyramids, grains.

Orientation:  $b=\mathfrak{b}$ ,  $c:\mathfrak{a}=-10^\circ$ .

Blue, colorless.

Pleochroism:  $\mathfrak{a}$ =colorless,  $\mathfrak{b}=\mathfrak{c}$ =sky-blue.

$\alpha=1.603$ ,  $\beta=1.632$ ,  $\gamma=1.639$ .

$\gamma-\alpha=0.036$ ,  $\gamma-\beta=0.007$ ,  $\beta-\alpha=0.029$ .

Dispersion: Strong,  $\rho < \nu$ .

$2E=135^\circ$  ca.

Unacted upon by acids.

Corundum is uniaxial and has 0.009 as maximum birefringence.

Blue cordierite has 0.009 as maximum birefringence.

Disthene and blue amphibole have good cleavage.

Dumortierite has good (100) cleavage,  $2V=30^\circ$ .

Sapphirine and serendibite have weak birefringence.

**Muscovite.**— $\text{Al}(\text{SiO}_4)_3\text{KH}_2\text{Al}_2$ ,  $H=2.0-2.5$ ,  $G=2.8-2.9$ .

Monoclinic. (—).

Cleavage: (001), good.

Habit: Laves, leafy aggregates.

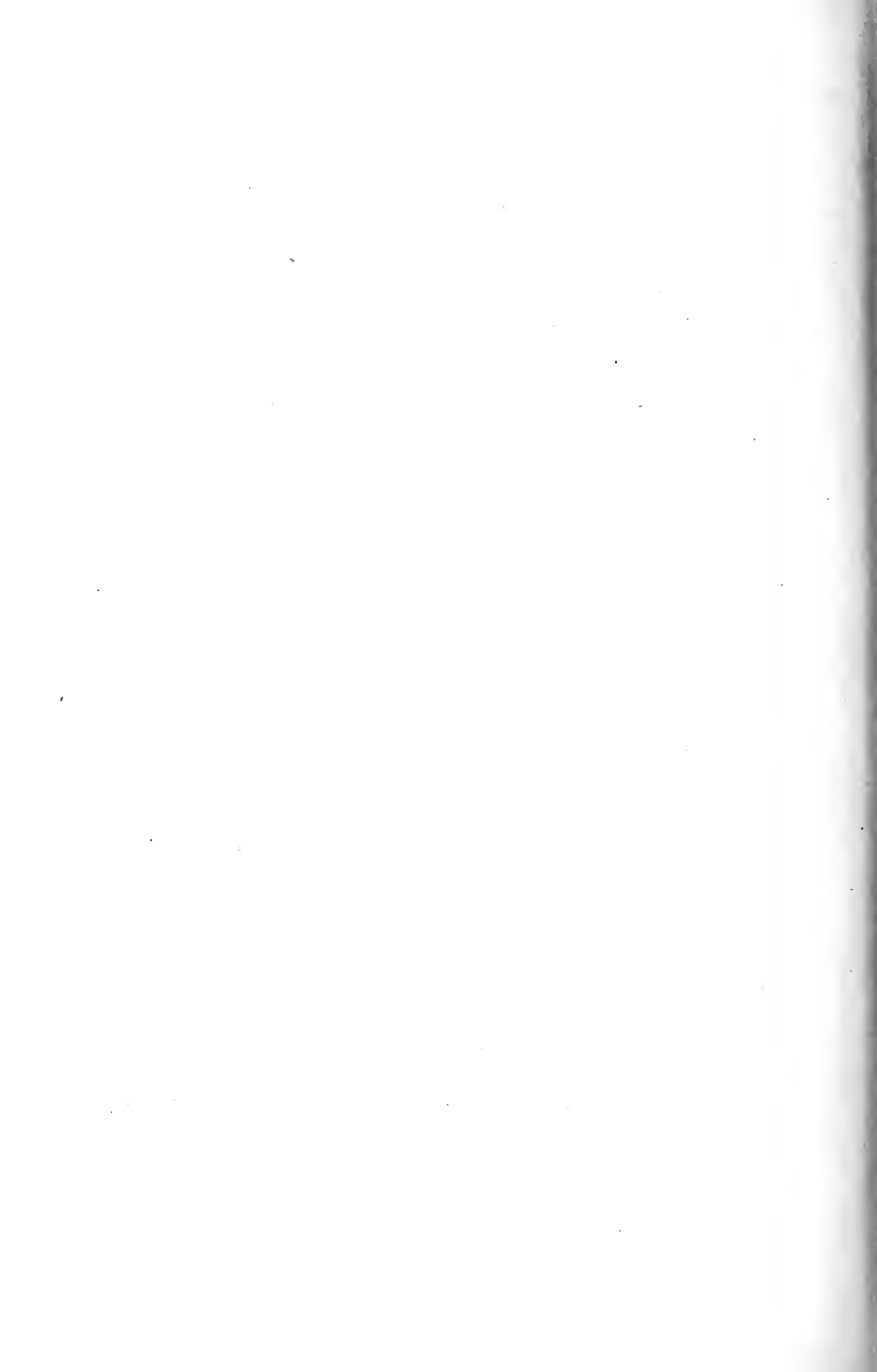
Elongation: At right angles to (001), lath-shaped. (+).

Orientation:  $b=\mathfrak{c}$ ,  $c:\mathfrak{a}=0^\circ$  to  $+2^\circ$ .

Colorless, greenish, yellowish.

Pleochroism: Weak or wanting.

Cut on line.





$\alpha = 1.563$ ,  $\beta = 1.598$ ,  $\gamma = 1.601$ .

$\gamma - \alpha = 0.038$ ,  $\gamma - \beta = 0.003$ ,  $\beta - \alpha = 0.035$ .

Dispersion: Weak  $\rho > \nu$ .

$2E = 60^\circ - 70^\circ$ .

Insoluble in HCl or  $H_2SO_4$ .

One of the mica group.

**Micas** can only be confused with other minerals which have perfect basal cleavage. The birefringence, very low in basal sections and high in sections showing cleavage, is very characteristic.

**Chlorites** have weak double refraction.

**Talc** has  $2E = 6^\circ - 20^\circ$ .

**Biotite** has  $2E$  generally much smaller than muscovite; also  $b = \mathfrak{b}$ .

**Lepidolite** and **paragonite** may be separated from muscovite by the Li flame test. See also Part II.

**Paragonite.**— $Al(SiO_4)_3Al_2NaH_2$ ,  $H = 2.0 - 2.5$ ,  $G = 2.8 - 2.9$

Monoclinic. (—).

Cleavage: (001), good.

Habit: Leaves, leafy aggregates.

Elongation: Perpendicular to (001), lath-shaped. (+).

Orientation:  $b = \mathfrak{r}$ ,  $c: a = 0^\circ$  to  $+2^\circ$ .

Colorless, greenish, yellowish.

Pleochroism: Weak or none.

Indices: Very similar to muscovite (see above).

Birefringence: Like muscovite (see above).

Dispersion: Weak,  $\rho > \nu$

$2E = 70^\circ$  ca.

Insoluble in acids.

One of the micas.

**Muscovite** and **lepidolite** are different chemically.

**Talc** has  $2E = 6^\circ - 20^\circ$ .

**Datolite.**— $HCaBSiO_5$ ,  $H = 5.0 - 5.5$ ,  $G = 2.9 - 3.0$ .

Monoclinic. (—).

No distinct cleavage.

Habit: Grains, rods.

Orientation:  $b = \mathfrak{b}$ ,  $c: a = +1^\circ$  to  $+4^\circ$ .

Colorless.

$\alpha = 1.625$ ,  $\beta = 1.653$ ,  $\gamma = 1.669$ .

$\gamma - \alpha = 0.044$ ,  $\gamma - \beta = 0.016$ ,  $\beta - \alpha = 0.028$ .

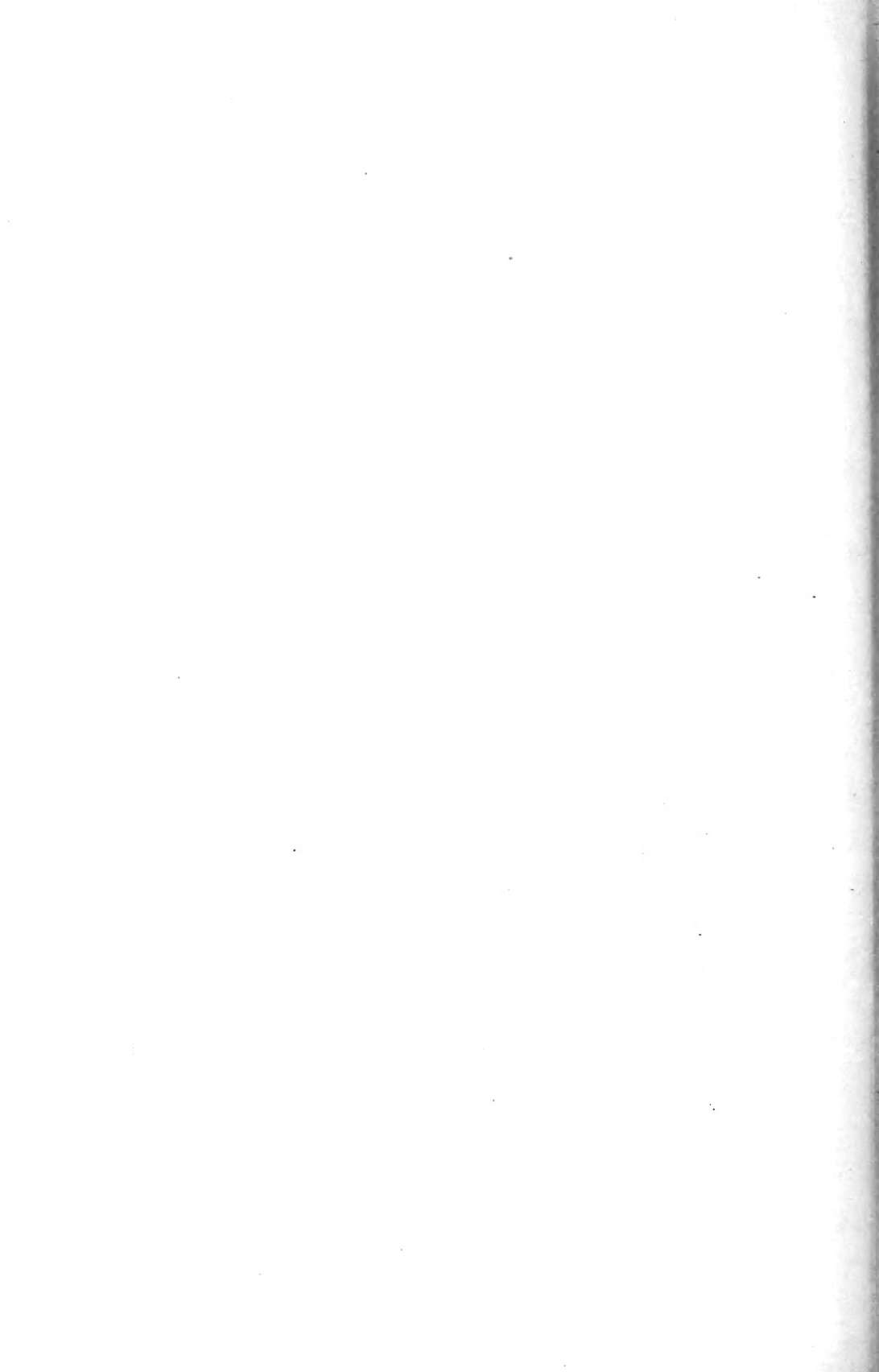
Dispersion: Weak,  $\rho > \nu$ .

$2V = 74^\circ$ .

Gelatinizes with HCl. B reaction.

**Pistacite** has cleavage, no reaction for B, and has lower birefringence.

Cut on line.



**Phlogopite.**—A magnesium mica, near biotite, but containing little Fe,

H=2.5–3.0, G=2.78–2.85.

Monoclinic. (–).

Cleavage: (001), good.

Habit: Leaves, leafy aggregates.

Elongation: At right angles to (001), lath-shaped. (+).

Orientation:  $b = \mathfrak{b}$ ,  $c: a = 0^\circ$  to  $+7^\circ$ .

Colorless, yellowish, brownish, greenish.

Pleochroism: Weak, with  $\mathfrak{r} > \mathfrak{b} > \mathfrak{a}$ .

$\alpha = 1.562$ ,  $\beta = 1.606$ ,  $\gamma = 1.606$ .

$\gamma - \alpha = 0.044$ ,  $\gamma - \beta = 0.0$ ,  $\beta - \alpha = 0.044$ .

Dispersion: Weak,  $\rho < \nu$ .

$2E = \text{small to } 0^\circ$ .

Completely decomposed by  $\text{H}_2\text{SO}_4$ , leaving the silica in thin flakes. One of the micas.

**Other micas:** Phlogopite has small to very small  $2V$ , and has symmetrical position of the plane of the optic axes.

**Other minerals,** see Part II.

**Grünerite.**— $\text{FeSiO}_3$ ,

H=5.0–6.0,

G=3.71.

Monoclinic. (–).

Cleavage: (110), good; (100), distinct; (010), poor. (110):(1 $\bar{1}$ 0) =  $55^\circ 49'$ .

Habit: Rods, leaves, grains.

Elongation: (110):(1 $\bar{1}$ 0), lath-shaped. (+).

Orientation:  $b = \mathfrak{b}$ ,  $c: \mathfrak{r} = -11^\circ$  to  $-15^\circ$ .

Colorless, brownish.

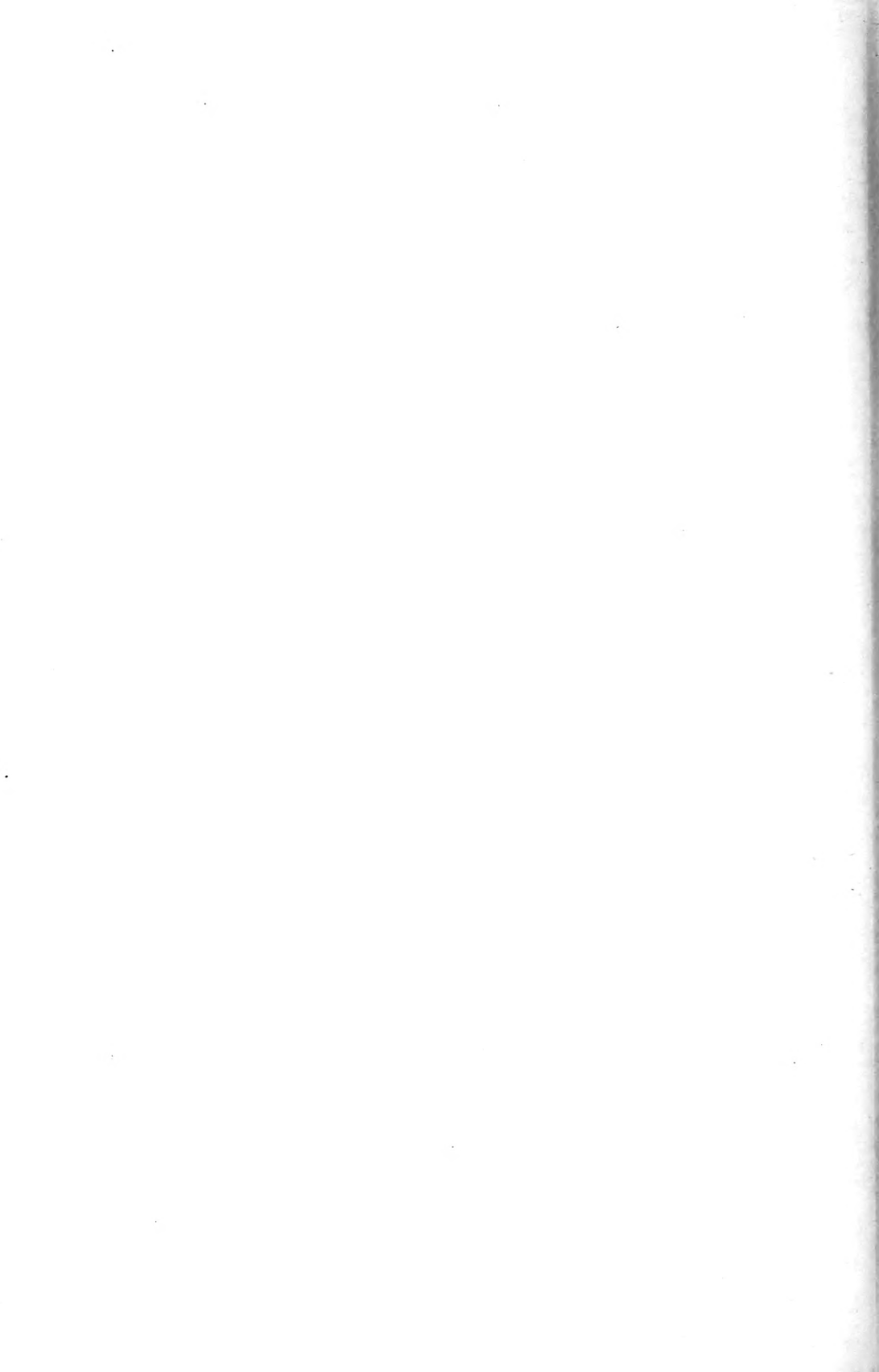
Pleochroism:  $\mathfrak{r} = \text{light brown}$ ;  $\mathfrak{b} = \mathfrak{a} = \text{colorless}$ .

$\beta = 1.73$ .

$\gamma - \alpha = 0.056$ .

$2V = \text{large}$ .

**Pyroxenes** differ in cleavage and have higher extinction angles.



**Celsian.**— $\text{BaAl}_2\text{Si}_2\text{O}_8$ ,  $H=6.0$ ,  $G=3.384$ .

Monoclinic. (+).

Cleavage: (001), (010), good.

Habit: Plates, prisms, grains. Carlsbad twinning common.

Elongation: (001):(010), lath-shaped; (110):(110), plates.

Orientation:  $b=b$ ,  $a:a=-62^\circ$ .

Colorless.

Non-pleochroic.

$\alpha=1.584$ ,  $\beta=1.589$ ,  $\gamma=1.594$ .

$\gamma-\alpha=0.010$ ,  $\gamma-\beta=0.005$ ,  $\beta-\alpha=0.005$ .

$2V=86^\circ$ .

Gelatinizes with HCl.

**Orthoclase** and **sanidine** have lower indices of refraction, smaller extinction angles, lower specific gravities, and no Ba.

**Plagioclase feldspars** show polysynthetic twinning, celsian never.

**Microcline** shows "grating structure" which never occurs in celsian.

See also Part II.

**Ottrelite.**— $\text{H}_2(\text{Fe}, \text{Mn})\text{Al}_2\text{SiO}_8$ ,  $H=6.0-7.0$ ,  $G=3.53-3.55$ .

Monoclinic. (+).

Cleavage: (001), good.

Habit: Leaves, plates. Tschermak twinning frequent.

Elongation: At right angles to (001), lath-shaped. (-).

Orientation:  $b=a$ ,  $c:c=0^\circ$  to  $20^\circ$ .

Blue, green, colorless.

Pleochroism:  $\epsilon$ =yellowish green, colorless;  $\eta$ =blue;  $\alpha$ =olive-green.

$\beta=1.74$ .

$\gamma-\alpha=0.010$ .

Dispersion: Strong,  $\rho > \nu$ . Strong dispersion,  $c:c_\rho > c:c_\nu$ .

$2E$ =large, very variable.

Hour-glass structure common.

Insoluble in HCl.

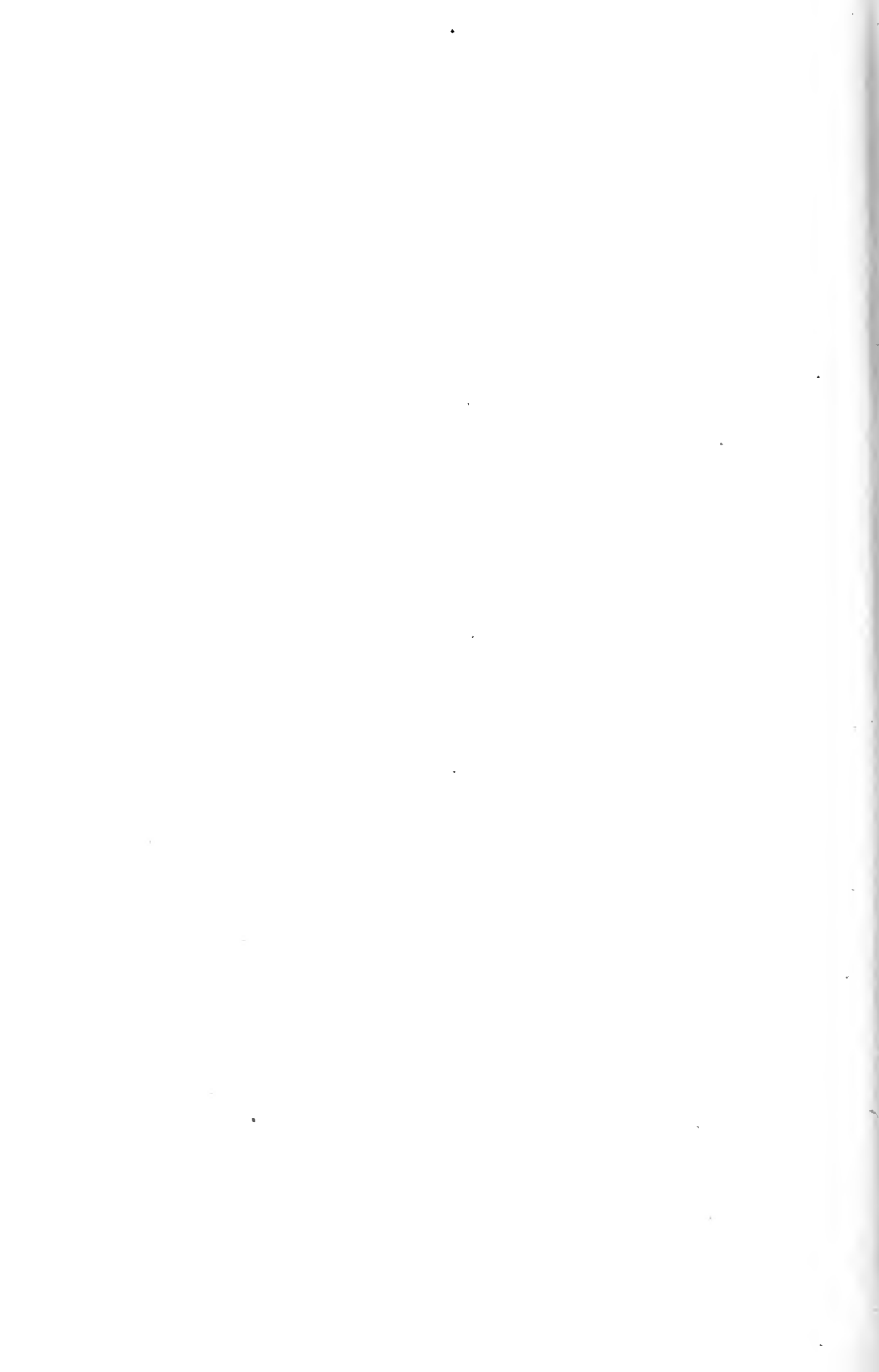
Almost exclusively confined to the phyllitic schists.

**Other minerals:** The high indices in combination with the low double refraction, the strong dispersion of the bisectrices and axes, and the peculiar pleochroism, separate the ottrelite group from all other minerals showing good (001) cleavage only.

**Mosandrite.** }  $\text{Ti, Zr, Th, Ce, Y, Fe, Mn, Ca, Mg, Na, K, F silicate, } H=4.0$   
**Johnstrupite.** } and more,  $G=3.10-3.29$  (Johns.),  $2.93-3.07$  (Mosan.).

Monoclinic. (+)

Cleavage: (100), good.



Habit: Tablets (100), elongated on *c*. Twinning (100) frequent.  
Elongation: (100):(010), lath-shaped. (-).

Orientation:  $b = \mathfrak{h}$ ,  $c : a = 3^\circ$ .

Grayish yellow to colorless.

Pleochroism: Not seen in thin sections.

$\alpha = 1.646$ ,  $\beta = 1.649$ ,  $\gamma = 1.658$ .

$\gamma - \alpha = 0.012$ ,  $\gamma - \beta = 0.009$ ,  $\beta - \alpha = 0.003$

Dispersion: Strong,  $\rho > \nu$ .

$2V = 70^\circ$ .  $2E_{na} = 128^\circ 37'$ .

Soluble in HCl with separation of  $\text{SiO}_2$ ; the dark-red solution on heating, gives off Cl, and becomes yellowish.

Rinkite has strong  $\rho < \nu$  dispersion, and the position of the plane of the optic axes is not symmetrical.

**Spodumene.**— $\text{LiAlSi}_2\text{O}_6$ ,  $H = 6.5-7.0$ ,  $G = 3.1-3.2$ .

Monoclinic. (+).

Cleavage: (110), good; (010), (100), distinct. (110):(1 $\bar{1}$ 0) =  $93^\circ 12'$ .

Habit: Prisms, tablets (100); (100) twinning.

Elongation: (110):(1 $\bar{1}$ 0), lath-shaped.

Orientation:  $b = \mathfrak{h}$ ,  $c : \mathfrak{c} = -23^\circ$  to  $-26^\circ$ .

Colorless. greenish.

Non-pleochroic in thin sections generally.

$a = \text{amethyst}$ ,  $\mathfrak{h} = \text{amethyst}$ ,  $\mathfrak{c} = \text{colorless}$ .

$\alpha = 1.660$ ,  $\beta = 1.666$ ,  $\gamma = 1.676$ .

$\gamma - \alpha = 0.016$ ,  $\gamma - \beta = 0.010$ ,  $\beta - \alpha = 0.006$ .

Dispersion:  $\rho < \nu$ .

$2V = 54^\circ-60^\circ$ .

Unaffected by acids.

One of the pyroxenes.

Other minerals, see Part II.

**Augite.**— $\text{CaMgSi}_2\text{O}_6$  with  $(\text{Mg,Fe})(\text{Al,Fe})_2\text{SiO}_6$ ,  $H = 5.0-6.0$ ,  $G = 3.2-3.6$ .

Monoclinic (+)

Cleavage: (110), good. (110):(1 $\bar{1}$ 0) =  $93^\circ$ .

Habit: Short prisms, grains, (100) twinning.

Elongation: (110):(1 $\bar{1}$ 0), lath-shaped.

Orientation:  $b = \mathfrak{h}$ ,  $c : \mathfrak{c} = -45^\circ$  to  $-55^\circ$ .

Green, brown, reddish, violet, rarely yellow, nearly colorless.

Pleochroism Usually weak, varies.

$\alpha = 1.698$ ,  $\beta = 1.704$ ,  $\gamma = 1.723$ .

$\gamma - \alpha = 0.025$ ,  $\gamma - \beta = 0.019$ ,  $\beta - \alpha = 0.006$ .

Dispersion: Weak,  $\rho > \nu$ .

$2V = 60^\circ$  ca. Distinct dispersion of bisectrices.

Unacted upon by acids.

Other pyroxenes, see Part II.

Olivine has different orientation of interference figure.





**Jadeite.**— $\text{NaAlSi}_2\text{O}_6$ ,  $H=6.5-7.0$ ,  $G=3.33-3.35$ .

Monoclinic. (+).

Cleavage: (110), good.  $(110):(1\bar{1}0)=93^\circ$ .

Habit: Short rod-like.

Elongation:  $(110):(110)$ , lath-shaped.

Orientation:  $b=b$ ,  $c:c=-33.5^\circ$ .

Colorless, light greenish.

Pleochroism: Wanting in thin sections.

$\beta=1.654$ .

$\gamma-\alpha=0.029$ .

Dispersion:  $\rho < \nu$ .

$2V=72^\circ$ .

Unaffected by acids even after fusion.

Other pyroxenes, see Part II.

**Diopside.**— $\text{CaMgSi}_2\text{O}_6$ ,  $H=5.0-6.0$ ,  $G=3.34$ .

Monoclinic. (+).

Cleavage: (110), good.  $(110):(110)=92^\circ 50'$ .

Habit: Prismatic, grains, twinning (100).

Elongation:  $(110):(110)$ , lath-shaped.

Orientation:  $b=b$ ,  $c:c=-39^\circ$ .

Colorless, greenish.

Pleochroism: Weak or wanting.

$\alpha=1.671$ ,  $\beta=1.678$ ,  $\gamma=1.700$ .

$\gamma-\alpha=0.029$ ,  $\gamma-\beta=0.022$ ,  $\beta-\alpha=0.007$ .

Dispersion: Weak,  $\rho > \nu$ .

$2V=59^\circ$ .

Unacted upon by acids.

All pyroxenes are characterized by right-angled cleavage on basal sections. Zonal structure is common with increasing green color outward and corresponding increase in the extinction angle.

Other pyroxenes, see Part II.

Olivine has different orientation of interference figure.

**Diallage.**—Composition near diopside, but often containing Al,  $H=4.0$ ,  $G=3.2-3.35$ .

Monoclinic. (+).

Cleavage: (110), (100), good.  $(110):(110)=92^\circ 50'$ .

Habit: Grains, short prisms, (100) twins frequent.

Elongation:  $(110):(110)$ , lath-shaped.

Orientation:  $b=b$ ,  $c:c=-39^\circ$ .

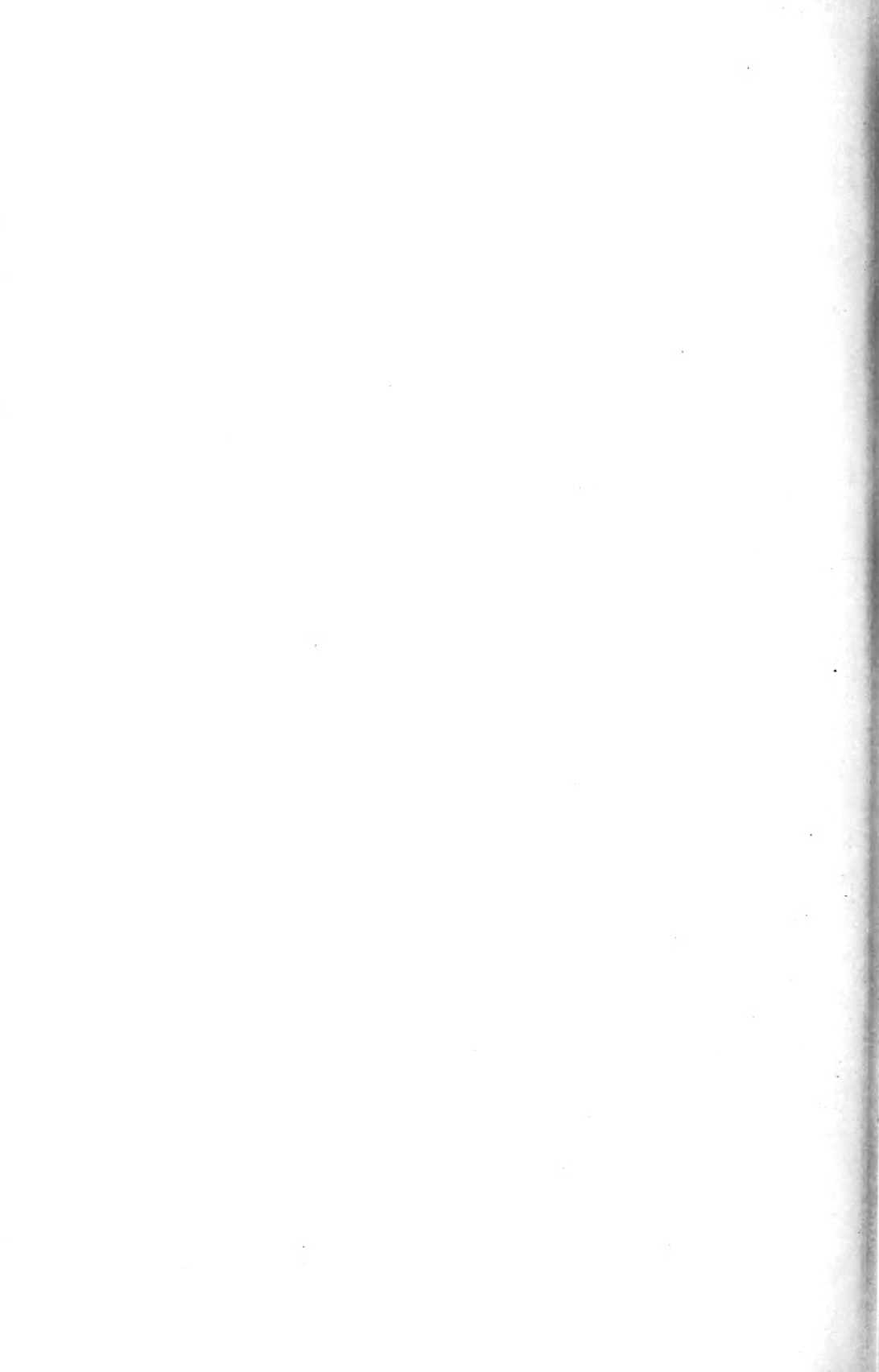
Colorless, greenish, brownish.

Pleochroism: Weak,  $b$ =yellowish,  $a=c$ =greenish

Indices: Like diopside.

Birefringence: Like diopside.

Dispersion: Weak,  $\rho > \nu$ .



$2V = 59^\circ$  and less.

Unacted upon by acids.

The complete (100) cleavage is most characteristic. Diallage is confined in occurrence to the gabbros, peridotites, and pyroxenites.

**Other pyroxenes**, see Part II.

Olivine has different orientation of interference figure.

**Piedmontite**.—Magnesia rich. See among the negative minerals above.

**Olivine**.— $(\text{Mg, Fe})\text{SiO}_4$ ,  $H = 6.5-7.0$ ,  $G = 3.27-3.45$ .

Orthorhombic. (+).

Cleavage: (010), (001), distinct; (100), poor. Generally shows heavy irregular cracks.

Habit: Isometric, short prisms, grains; twins (011) and (012) rare.

Orientation:  $a = c$ ,  $b = a$ .

Greenish, yellowish, reddish, colorless.

Pleochroism: Wanting or weak in yellow and red tones.

$\alpha = 1.654$ ,  $\beta = 1.670$ ,  $\gamma = 1.689$ .

$\gamma - \alpha = 0.035$ ,  $\gamma - \beta = 0.019$ ,  $\beta - \alpha = 0.016$ .

Dispersion: Distinct,  $\rho < \nu$ .

$2V = 88^\circ$  ca.

Gelatinizes slowly in HCl.

**Diopside** has two equally good cleavages to which the extinction is inclined; olivine has two very unequal cleavages to which the extinction is parallel in the principal zone. Diopside does not gelatinize with HCl.

**Fayalite** has  $2V = 50^\circ$ , has higher birefringence, and is (-).

**Forsterite** has lower indices and occurs as a contact mineral in metamorphosed limestones.

**Monticellite** is (-) and has  $2V = 37.5^\circ$ .

**Augite** and **diallage**, when in sections showing parallel extinction, have different orientation of interference figures.

**Pectolite**.— $\text{NaHCa}_2\text{Si}_3\text{O}_9$ ,  $H = 4.5-5.0$ ,  $G = 2.74-2.88$ .

Monoclinic. (+).

Cleavage: (100), good; (001), distinct.  $(100):(001) = 84.5^\circ$ .

Habit: Tablets; rods along  $b$ .

Elongation: Laths, tabular. (+).

Orientation:  $b = c$ ,  $c : a = -5^\circ$ .

Colorless

Non-pleochroic.

Index:  $n = 1.61$  ca.

$\gamma - \alpha = 0.038$

$2V = 60^\circ$ .

Soluble in HCl.

**Wollastonite** is (-), has ( $\pm$ ) elongation, lower double and higher indices of refraction, and  $c : a = +32^\circ$ .

Cut on line.



**Monazite**—(Ce,La,Di)PO<sub>4</sub>,                      H = 5.5,                      G = 4.9–5.3.

Monoclinic. (+).

Cleavage: (100), (010), distinct.

Habit: Tablets, often elongated on *b*.

Elongation: (001):(100), short laths. (–).

Orientation. *b* = *a*, *c*:*r* = 2° to 6°.

Colorless, yellowish.

Non-pleochroic in thin sections.

$\alpha = 1.796$ ,  $\beta = 1.797$ ,  $\gamma = 1.841$ .

$\gamma - \alpha = 0.045$ ,  $\gamma - \beta = 0.044$ ,  $\beta - \alpha = 0.001$ .

Dispersion: Weak,  $\rho < \nu$ .

$2E = 21^\circ$  to  $36^\circ$ .

Soluble with difficulty in HCl, leaving a white residue.

**Olivine** has  $2V = 88^\circ$  ca. and contains no P.

**Titanite** has strong dispersion  $\rho > \nu$  and contains no P, extinction +  $39^\circ$ , weak pleochroism, and much higher birefringence.

**Titanite**.—CaSiTiO<sub>6</sub>,                      H = 5.0–5.5,                      G = 3.4–3.56.

Monoclinic. (+).

Cleavage: (110), distinct. (110):(1 $\bar{1}$ 0) =  $46^\circ 8'$ .

Habit: Prisms, rhombs, grains, rods.

Orientation: *b* = *h*, *c*:*r* = +  $39^\circ$ .

Colorless, yellowish, reddish, brownish.

Pleochroism: Weak, *r* > *h* > *a*.

$\alpha = 1.913$ ,  $\beta = 1.921$ ,  $\gamma = 2.054$ .

$\gamma - \alpha = 0.147$ ,  $\gamma - \beta = 0.133$ ,  $\beta - \alpha = 0.008$ .

Dispersion: Very strong,  $\rho > \nu$ .

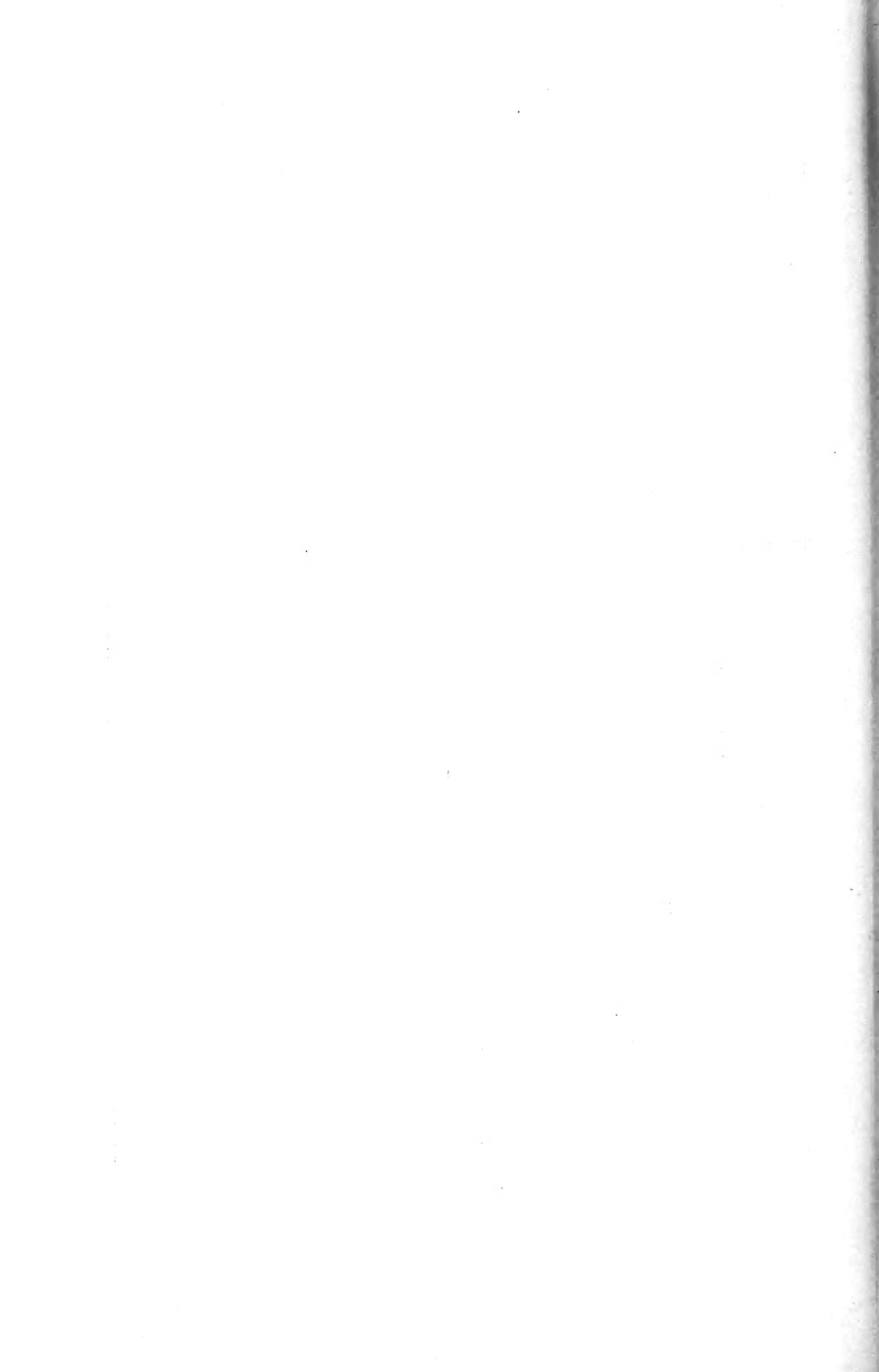
$2E_{na} = 45^\circ$ – $68^\circ$ .

Very slightly affected by HCl.

**Monazite** has lower birefringence, weak dispersion, and low extinction angle.

**Brookite** has parallel extinction,  $2V = 0^\circ$ – $23^\circ$ , and great difference in the birefringence in the two directions;  $\gamma - \alpha = 0.158$ , while  $\beta - \alpha = 0.003$ .

**Rutile**, **xenotime**, **hussakite**, and **cassiterite** give no Ca reactions.



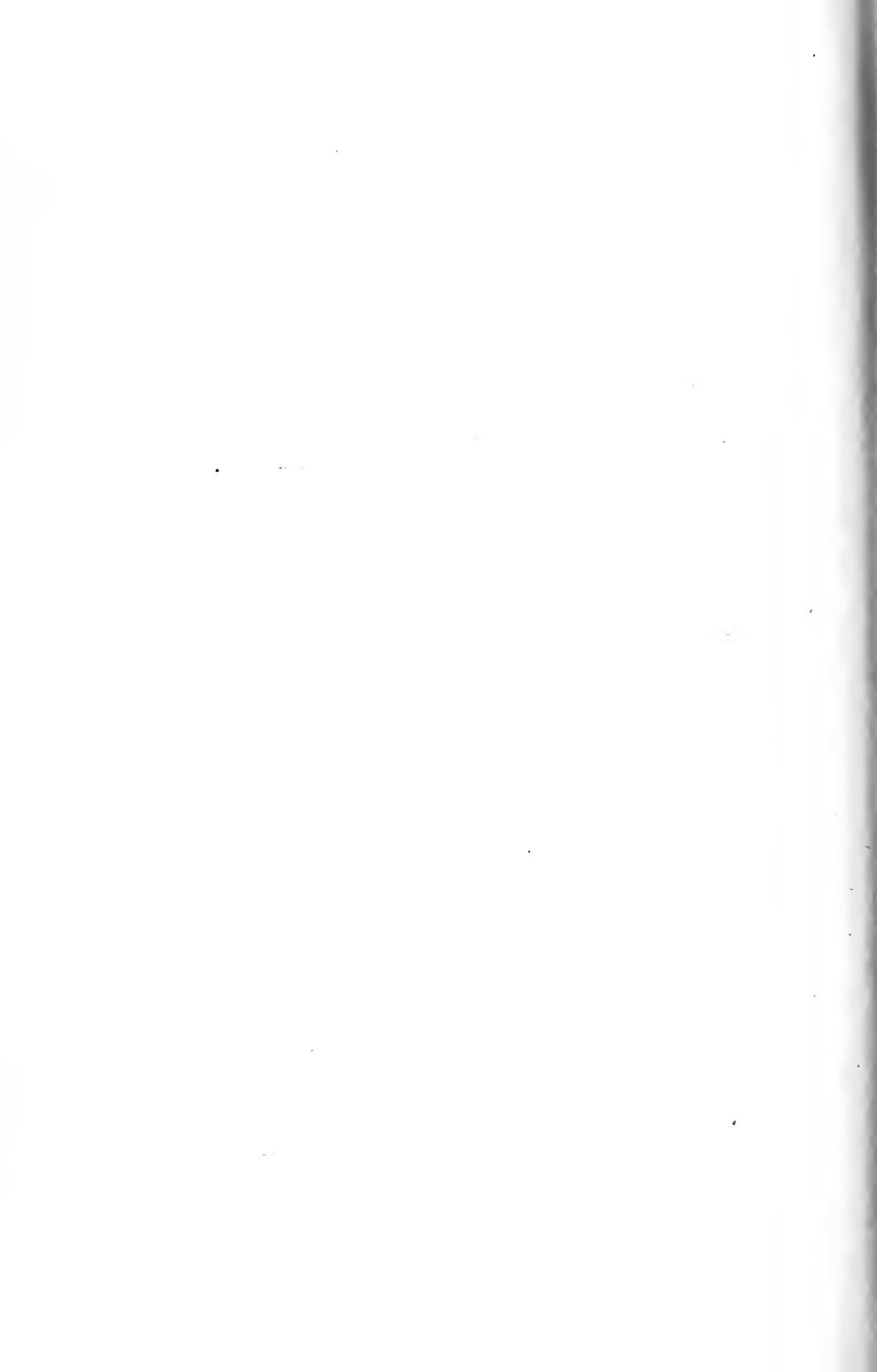
The mineral is **anisotropic**.

**Inclined** extinction.

**Colored.**

**COLORED.**

*Cut on line.*





The mineral is **anisotropic**.

**Inclined** extinction.

**Colored**.

**Non-pleochroic**.

**NON-PLEOCHROIC.**

*Cut on line.*



The mineral is **anisotropic**.

Inclined extinction.

Colored.

Non-pleochroic.

Maximum birefringence is less  
than that of quartz.

BIREFRINGENCE < QUARTZ.

*Cut on line.*



**Lepidolite.**— $\text{Al}(\text{SiO}_4)_3\text{Al}_2\text{KLiH} + \text{Al}(\text{Si}_3\text{O}_8)_3\text{K}_3\text{Li}_3(\text{AlF}_2)_2$ ,  $H = 2.5\text{--}4.0$ ,  $G = 2.8\text{--}2.9$ .

Monoclinic. (—).

Cleavage: (001), good.

Habit: Leaves, leafy aggregates.

Elongation: At right angles to (001), lath-shaped. (+).

Orientation:  $b = \tau$ ,  $c: a = 0^\circ$  to  $+2^\circ$ ; or rarely  $b = \tau$ ,  $c: a = 0^\circ$  to  $+2^\circ$ .

Colorless, reddish

Pleochroism: Weak or none.

$\beta = 1.598$ ,  $\gamma = 1.605$ .

$\gamma - \beta = 0.007$ .

Dispersion: Weak,  $\rho \gtrsim \nu$ .

$2E = 32^\circ\text{--}84^\circ$ .

Insoluble in acids.

Muscovite and paragonite do not give Li flame.

See also Part II.

**Kaolin.**— $\text{H}_4\text{Al}_2\text{Si}_2\text{O}_9$ ,  $H = 2.5\text{--}3.0$ ,  $G = 2.6\text{--}2.65$ .

Monoclinic. (—).

Cleavage: (001), good.

Habit: Leaves, scales, leafy aggregates.

Elongation: At right angles to (001); lath-shaped. (+).

Orientation:  $b = \tau$ ,  $c: a = +13^\circ$  ca.

Colorless, yellowish, dull clouded.

Pleochroism: None.

$\beta = 1.54$  ca.

$\gamma - \alpha = 0.008$ .

$2V = 90^\circ$ , more or less. Friedel found in kaolin from Miramont

$2V$  very small to  $0^\circ$ .

Insoluble in HCl.

Muscovite and hydrargillite have higher double refraction.

Chemically separated by presence of K in muscovite and no  $\text{SiO}_2$  in hydrargillite.

**Antigorite.**— $\text{H}_4(\text{Mg}, \text{Fe})_3\text{Si}_2\text{O}_9$ ,  $H = 2.5$ ,  $G = 2.622$ .

Orthorhombic. (—).

Habit: Lamellæ, leaves, scales.

Elongation: At right angles to (100), lath-shaped. (+).

Orientation:  $a = a$ ,  $b = \tau$ .

Greenish, colorless, yellowish.

Non-pleochroic.

$\alpha = 1.560$ ,  $\beta = 1.570$ ,  $\gamma = 1.571$ .

$\gamma - \alpha = 0.011$ ,  $\gamma - \beta = 0.001$ ,  $\beta - \alpha = 0.010$ .

Dispersion:  $\rho > \nu$ .

$2E = 16^\circ\text{--}98^\circ$ .

In boiling HCl silica separates.

Pennine is pleochroic, has lower double and higher indices of refraction.

Ordinary serpentine is (+).



**Kelyphite.**—Alteration product of pyrope. Becke believes it to be composed of picotite and hornblende.

Habit: Rims around pyrope, radial fibres.

Birefringence is weak.

**Glauconite.**—A hydrous silicate of K, Fe, and Al, with Mg and Ca,  $H=2.0$ ,  $G=2.2-2.4$

Biaxial.

Rounded bodies, small spheres, irregular, and aggregates. No cleavage.

Yellowish green, bluish green, dark green.

Pleochroism: None, or green and yellow.

Index: Higher than quartz.

Birefringence: Low to medium.

$2E=0$  to  $40^\circ$ .

Slowly soluble in boiling HCl, leaving a residue of  $\text{SiO}_2$  in the form of spherules.

Resembles chlorite.

**Clinozoisite.**— $\text{Al}(\text{SiO}_4)_3(\text{Al}, \text{Fe})_2\text{Ca} \cdot \text{CaO}11$ ,  $H=6.5$ ,  $G=3.3-3.5$ .

Monoclinic. (+).

Cleavage: (001), good; (100), distinct.  $(001):(100)=64^\circ 37'$ .

Habit: Prisms and rods elongated on  $b$  grains. (100) twinning.

Elongation:  $(001):(100)$ , lath-shaped. ( $\pm$ ).

Orientation:  $b=\mathfrak{h}$ ,  $c:\mathfrak{a}=-3^\circ$ .

Colorless, reddish.

Pleochroism: Weak.

$\alpha=1.716$ ,  $\beta=1.718$ ,  $\gamma=1.724$ .

$\gamma-\alpha=0.008$ ,  $\gamma-\beta=0.006$ ,  $\beta-\alpha=0.002$ .

Dispersion: Strong,  $\rho < \nu$ .

$2V=80^\circ-90^\circ$ .

An iron-poor or free epidote. Pistacite is the iron-rich epidote.

Abnormal interference colors. Strong dispersion of the bisectrices.

Insoluble in HCl.

Zoisite has parallel extinction and smaller  $2V$ .

**Clinochlore.**—Mg, Fe, Al silicate,  $H=2.0-2.5$ ,  $G=2.71$ .

Monocline. (+).

Cleavage: (001), good.

Habit: Leaves, scales, leafy aggregates. Twinning common.

Elongation: At right angles to (001), lath-shaped. (—).

Orientation:  $b=\mathfrak{h}$ ,  $c:\mathfrak{r}=-2^\circ$  to  $-9^\circ$ .

Green.

Pleochroism:  $\mathfrak{a}$  and  $\mathfrak{h}=\text{green}$ ;  $\mathfrak{r}=\text{yellow}$ .

$\alpha=1.585$ ,  $\beta=1.586$ ,  $\gamma=1.596$ .

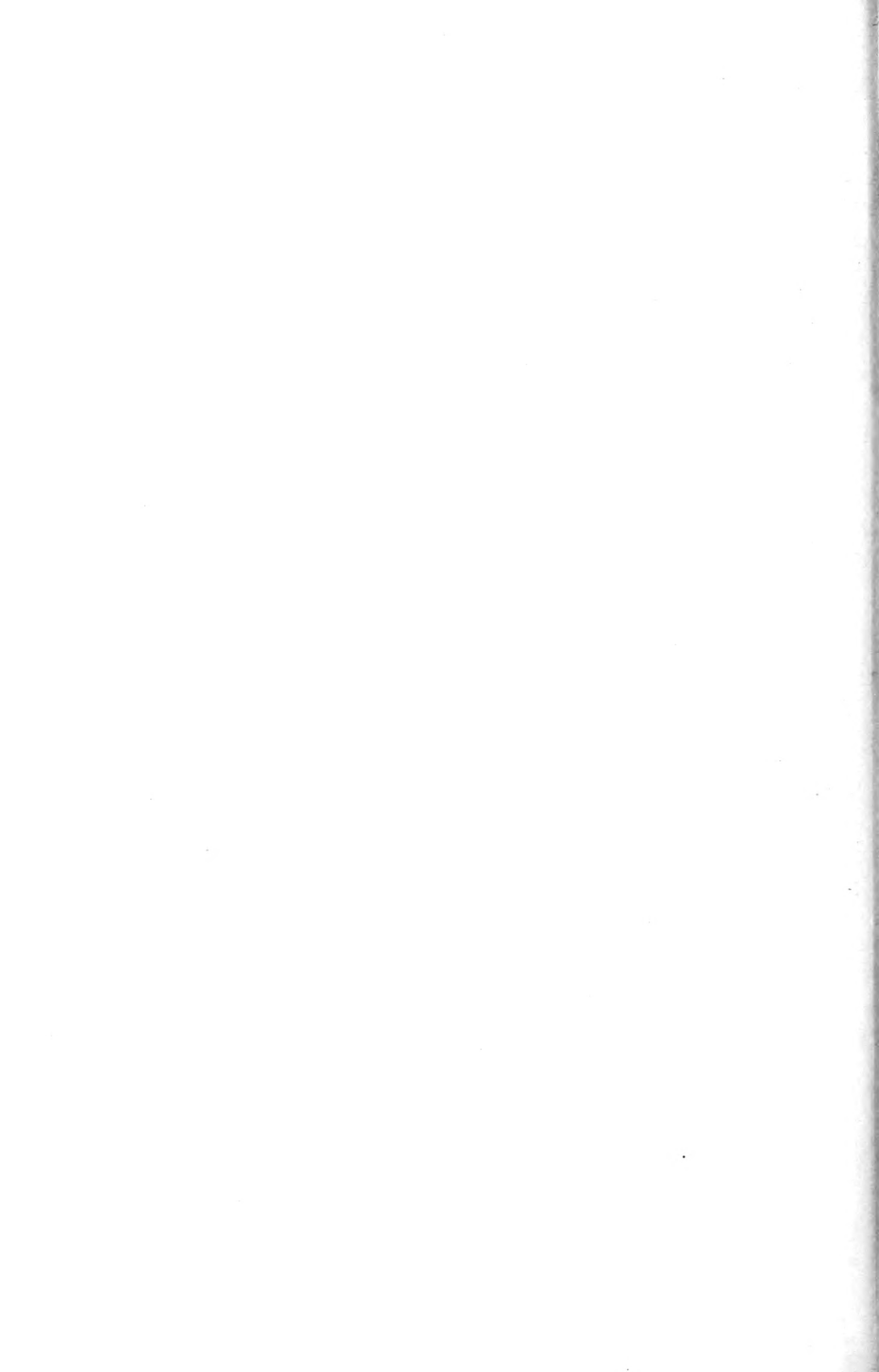
$\gamma-\alpha=0.011$ ,  $\gamma-\beta=0.010$ ,  $\beta-\alpha=0.001$ .

Dispersion:  $\rho < \nu$ .

$2E=32^\circ-90^\circ$

Pennine is ( $\pm$ ),  $2E=0^\circ-61^\circ$ ,  $c:\mathfrak{r}=0^\circ$ ,  $\gamma-\alpha=0.002$ .

Cut on line.





The mineral is **anisotropic**.

**Inclined** extinction.

**Colored**.

**Non-pleochroic**.

**Maximum birefringence** is greater  
than that of quartz.

BIREFRINGENCE > QUARTZ.

*Cut on line.*



**Axinite**— $\text{Ca}_7\text{Al}_4\text{B}_2(\text{SiO}_4)_8$ ,  $\text{H}=6.5-7.0$ ,  $\text{G}=3.27-3.29$ .  
 Triclinic. (—).  
 Cleavage: (010), distinct.  
 Habit: Grains, tablets.  
 Orientation: Plane of the optic axes makes an angle of  $24^\circ 40'$  with the edge (111), (111): and of  $40^\circ$  with (111):(110).  
 Colorless, yellowish, brownish, violet.  
 Pleochroism: Weak or not noticeable in thin sections.  
 $\alpha=1.685$ ,  $\beta=1.692$ ,  $\gamma=1.695$ .  
 $\gamma-\alpha=0.010$ ,  $\gamma-\beta=0.003$ ,  $\beta-\alpha=0.007$ .  
 Dispersion: Distinct,  $\rho < \nu$ .  
 $2E$ =large and variable.

But slightly affected by acids; after fusion gelatinizes with HCl.

**Other minerals:** Axinite is separated by the characteristic occurrence of acute-angled edges, by the combination of strong indices with weak double refraction, and good cleavage. Chemically by the presence of B.

**Antigorite**.— $\text{H}_2(\text{Mg}, \text{Fe})_3\text{Si}_2\text{O}_7$ ,  $\text{H}=2.5$ ,  $\text{G}=2.622$ .  
 Orthorhombic. (—).  
 Habit: Lamellæ, leaves, scales.  
 Elongation: At right angles to (100), lath-shaped. (+).  
 Orientation:  $a=a$ ,  $b=c$ .  
 Greenish, colorless, yellowish.  
 Non-pleochroic.  
 $\alpha=1.560$ ,  $\beta=1.570$ ,  $\gamma=1.571$ .  
 $\gamma-\alpha=0.011$ ,  $\gamma-\beta=0.001$ ,  $\beta-\alpha=0.010$ .  
 Dispersion:  $\rho > \nu$ .  
 $2E=16^\circ-98^\circ$ .

In boiling HCl silica separates.

**Pennine** is pleochroic, has lower double and higher indices of refraction.

**Ordinary serpentine** is (+).

**Disthene**.— $\text{Al}_2\text{SiO}_5$ ,  $\text{H}=4.0-7.0$ ,  $\text{G}=3.56-3.67$ .  
 Triclinic. (—).  
 Cleavage: (100), good; (010), distinct. (100):(010)= $74^\circ$ .  
 Habit: Prisms, tablets.  
 Elongation: (100):(010), lath-shaped. (+).  
 Orientation:  $a$ =nearly at right angles to (100),  $c$ =inclined  $30^\circ$  on (100) against edge (100):(010).  
 Colorless, blue.  
 Pleochroism: Weak, between blue and colorless.  
 $\alpha=1.717$ ,  $\beta=1.722$ ,  $\gamma=1.729$ .  
 $\gamma-\alpha=0.012$ ,  $\gamma-\beta=0.007$ ,  $\beta-\alpha=0.005$ .  
 Dispersion:  $\rho > \nu$ .  
 $2V=82^\circ$ .



Insoluble in acids.

Does not occur in eruptive rocks, but in crystalline schists and gneisses.

**Sillimanite** and **andalusite** are orthorhombic, have parallel extinction, and different cleavage.

**Sillimanite** has higher double refraction and smaller  $2V$  ( $31^\circ$ – $42^\circ$ ).

**Topaz** has basal cleavage, and is orthorhombic.

**Zoisite** and **colorless epidote** have different position of axial plane in relation to cleavage.

**Serendibite** and **dumortierite** have different pleochroism.

**Blue amphibole** has different cleavage and lower indices of refraction.

**Rosenbuschite**.— $2\text{Na}_2\text{ZrO}_2\cdot\text{F}_2\cdot 6\text{CaSiO}_3\cdot\text{TiSiO}_3\cdot\text{TiO}_2$ ,  $H=5.0$ – $6.0$ ,  $G=3.30$ – $3.315$ .

Monoclinic. ( $\pm$ ?).

Cleavage: (001), good; (100), distinct. (001):(100) =  $78^\circ$ .

Habit: Rods along  $b$ .

Elongation: Narrow laths. (–).

Orientation:  $b = a$ ,  $c : r = +13^\circ$ .

Colorless, light greenish yellow.

Pleochroism: Not marked.  $r > b > a$

Index:  $n = 1.65$  ca.

$\gamma - \alpha = 0.026$  ca.

$2V = \text{near } 90^\circ$ .

Easily attacked by HCl.

**Sillimanite** and **carpholite** are not affected by HCl and have (+) elongation.

**Wollastonite** has ( $\pm$ ) elongation, lower double refraction, and higher extinction angle.

**Pectolite** has (+) elongation.

**Actinolite**.— $(\text{FeMg})_3\text{Si}_4\text{O}_{12}$ ,  $H=5.0$ – $6.0$ ,  $G=3.0$ – $3.2$ .

Monoclinic. (–).

Cleavage: (100), good; (100), distinct; (010), poor. (110):(110) =  $55^\circ 49'$ .

Habit: Rods, leaves, grains. Twinning (100) occurs.

Elongation: (110):(110), lath-shaped. (+).

Orientation:  $b = b$ ,  $c : r = -15^\circ$ .

Green.

Pleochroism: Hardly noticeable in thin sections.  $r = \text{green}$ ;

$b$  and  $a = \text{yellowish green}$ .

$\alpha = 1.607$ ,  $\beta = 1.624$ ,  $\gamma = 1.634$ .

$\gamma - \alpha = 0.027$ ,  $\gamma - \beta = 0.010$ ,  $\beta - \alpha = 0.017$ .

Dispersion: Weak,  $\rho > \nu$ .

$2V = 80^\circ$ .

*Cut on line.*



But slightly acted upon by HCl.

**Pistacite** has trace of the plane of the optic axes at right angles to the cleavage, and ( $\pm$ ) elongation.

**Pyroxenes** differ in cleavage and have higher extinction angle. See Part II.

**Muscovite.**— $\text{Al}(\text{SiO}_4)_3\text{KH}_2\text{Al}_2$ ,  $H=2.0-2.5$ ,  $G=2.8-2.9$ .

Monoclinic. (—).

Cleavage: (001), good.

Habit: Leaves, leafy aggregates.

Elongation: At right angles to (001), lath-shaped. (+).

Orientation:  $b=c$ ,  $c:a=0^\circ$  to  $2^\circ$ .

Colorless, greenish, yellowish.

Pleochroism: Weak or wanting.

$\alpha=1.563$ ,  $\beta=1.598$ ,  $\gamma=1.601$ .

$\gamma-\alpha=0.038$ ,  $\gamma-\beta=0.003$ ,  $\beta-\gamma=0.035$ .

Dispersion: Weak,  $\rho > \nu$ .

$2E=60^\circ-70^\circ$ .

Insoluble in HCl or  $\text{H}_2\text{SO}_4$ .

One of the mica group.

**Micas** can only be confused with other minerals which have perfect basal cleavage. The birefringence, very low in basal sections and high in sections showing cleavage, is very characteristic for the micas.

**Chlorites** have weak double refraction.

**Talc** has  $2E=6^\circ-20^\circ$ .

**Biotite** has  $2E$  generally much smaller than muscovite; also  $b=b$ .

**Lepidolite** and **paragonite** may be separated from muscovite by the Li flame test.

**Paragonite.**— $\text{Al}(\text{SiO}_4)_3\text{Al}_2\text{NaH}_2$ ,  $H=2.0-2.5$ ,  $G=2.8-2.9$ .

Monoclinic. (—).

Cleavage: (001), good.

Habit: Leaves, leafy aggregates.

Elongation: Perpendicular to (001), lath-shaped. (+).

Orientation:  $b=c$ ,  $c:a=0^\circ$  to  $+2^\circ$ .

Colorless, greenish, yellowish.

Pleochroism: Weak or none.

Indices: Very similar to muscovite (see above).

Birefringence: Like muscovite (see above).

Dispersion: Weak,  $\rho > \nu$ .

$2E=70^\circ$  ca.

Insoluble in acids

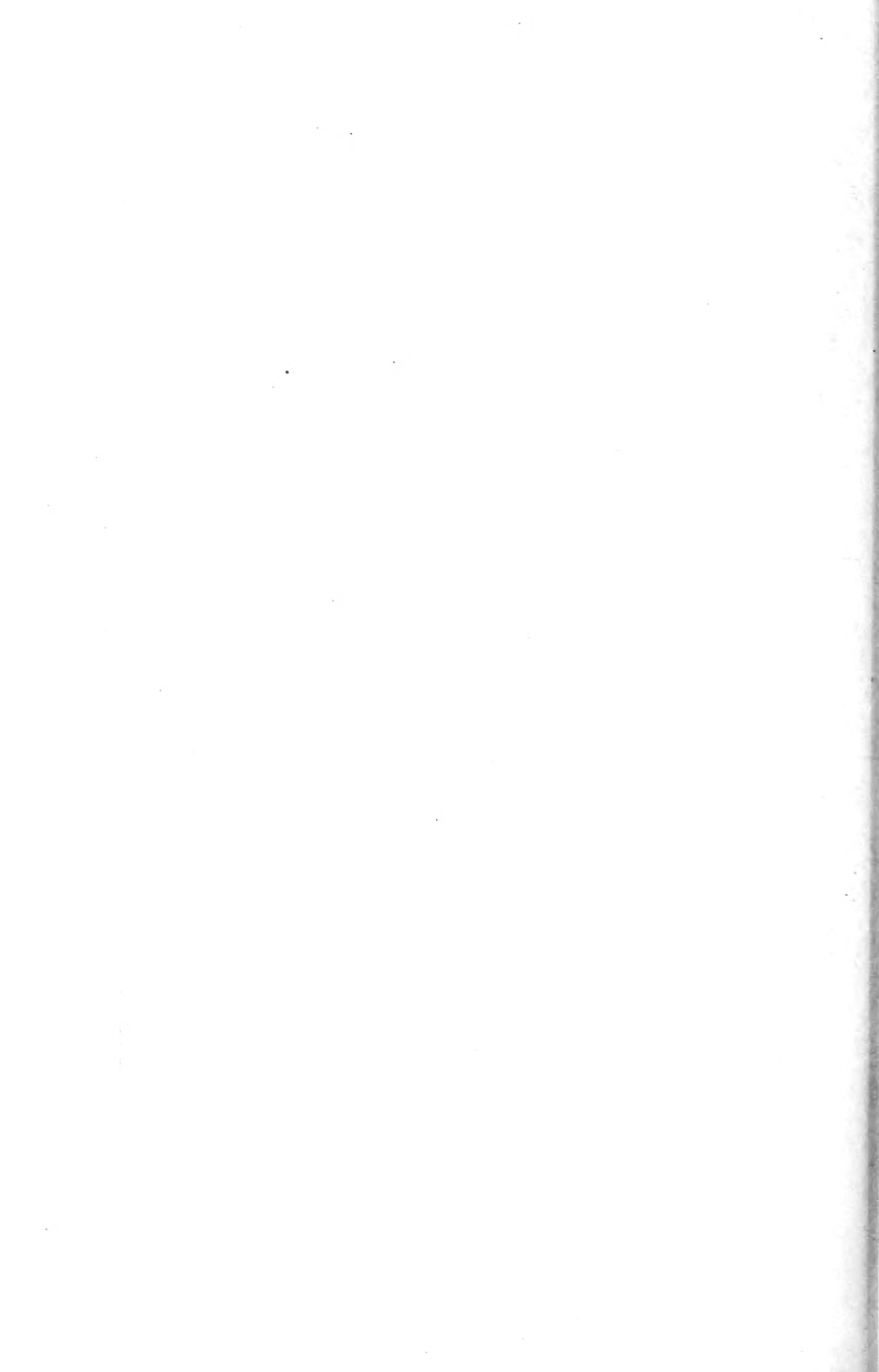
One of the micas.

**Muscovite** and **lepidolite** are different chemically.

**Talc** has  $2E=6^\circ-20^\circ$ .

See also Part II.

Cut on line.





**Phlogopite.**—A magnesium mica, near biotite, but containing little Fe,

H=2.5–3.0, G=2.78–2.85.

Monoclinic. (–).

Cleavage: (001), good.

Habit. Leaves, leafy aggregates.

Elongation: At right angles to (001), lath-shaped. (+).

Orientation:  $b = \mathbf{b}$ ,  $c : a = 0^\circ$  to  $+7^\circ$ .

Colorless, yellowish, brownish, greenish.

Pleochroism: Weak with  $\mathbf{c} > \mathbf{b} > \mathbf{a}$ .

$\alpha = 1.562$ ,  $\beta = 1.606$ ,  $\gamma = 1.606$ .

$\gamma - \alpha = 0.044$ ,  $\gamma - \beta = 0.0$ ,  $\beta - \alpha = 0.044$ .

Dispersion: Weak,  $\rho > \nu$ .

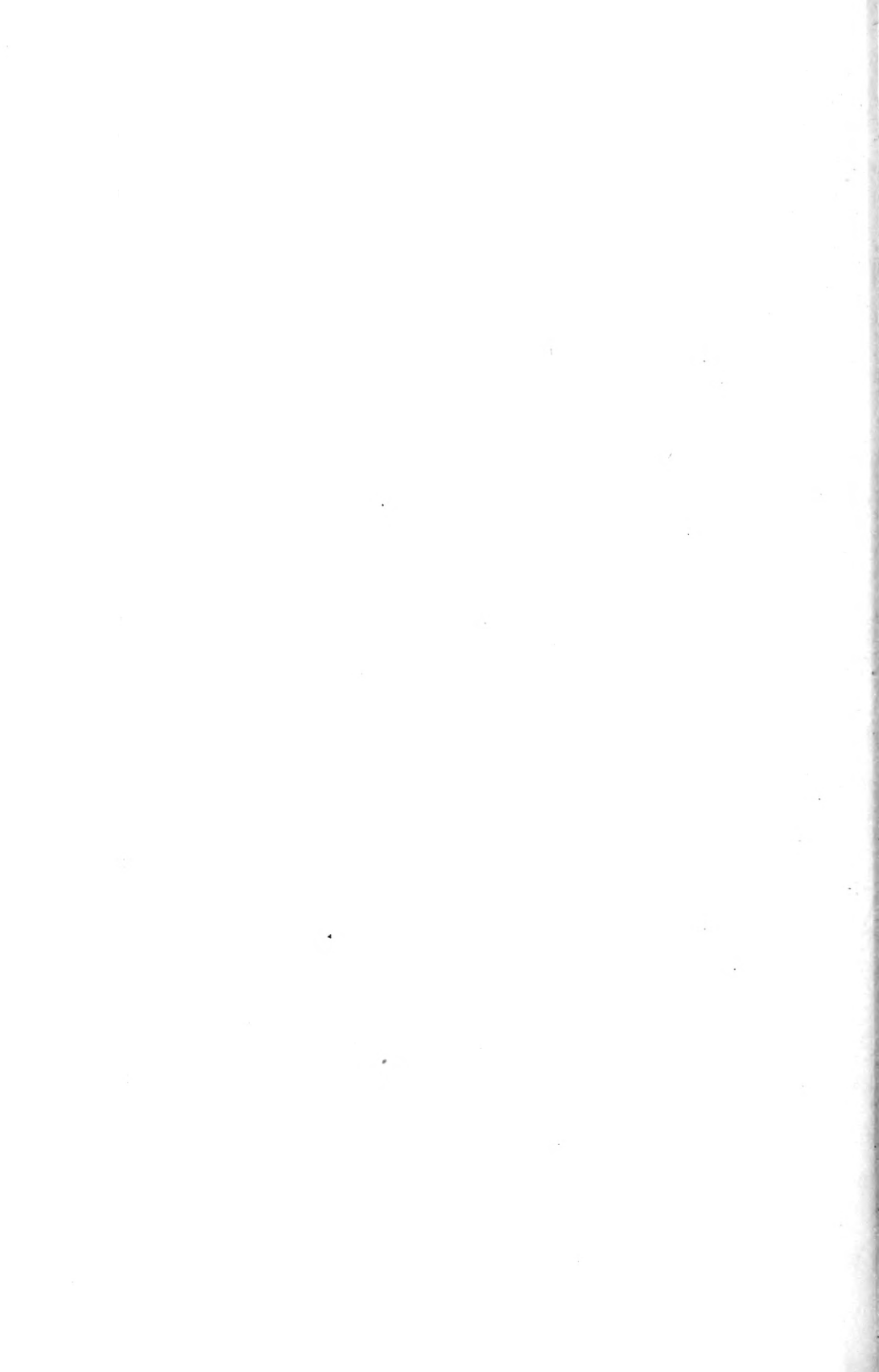
$2E$  = small to  $0^\circ$ .

Completely decomposed by  $\text{H}_2\text{SO}_4$ , leaving the silica in thin flakes. One of the mica group.

**Other micas:** Phlogopite has small to very small  $2V$ , and has symmetrical position of the plane of the optic axes.

**Other minerals,** see Part II.

*Cut on line.*



Mosandrite. } Ti,Zr,Th,Ce,Y,Fe,Mn,Ca,Mg,Na,K,F silicate, H = 4.0 and more,  
 Johnstrupite. } G = 3.10-3.29 (Johns.), 2.93-3.07 (Mosan.).

Monoclinic (+)

Cleavage: (100), good.

Habit: Tablets (100), elongated on *c*; twinning (100) frequent.

Elongation: (100):(010), lath-shaped. (-).

Orientation:  $b = \mathfrak{b}$ ,  $c : a = 3^\circ$ .

Grayish-yellow to colorless.

Pleochroism: Not seen in thin sections.

$\alpha = 1.646$ ,  $\beta = 1.649$ ,  $\gamma = 1.658$ .

$\gamma - \alpha = 0.012$ ,  $\gamma - \beta = 0.009$ ,  $\beta - \alpha = 0.003$ .

Dispersion: Strong,  $\rho > \nu$ .

$2V = 70^\circ$ .  $2E_{na} = 128^\circ 37'$ .

Soluble in HCl with separation of  $\text{SiO}_2$ ; the dark-red solution on heating gives off Cl and becomes yellowish.

Rinkite has strong  $\rho < \nu$  dispersion, and the position of the plane of the optic axes is not symmetrical.

Serpentine.— $\text{H}_4(\text{Mg,Fe})_3\text{Si}_2\text{O}_{10}$ , H = 3.0-4.0, G = 2.5-2.7.

Probably orthorhombic. (+).

Cleavage: Generally none.

Habit: Threads, leaves, aggregates, massive pseudomorphs.

Elongation: (110):(110), thread-like. (+).

Orientation:  $b = a$ ,  $c = c$ .

Green, yellow, colorless.

Pleochroism: Very feeble.

Index:  $n = 1.54$  ca.

$\gamma - \alpha = 0.013$ .

Dispersion:  $\rho > \nu$ .

$2E = 16^\circ - 50^\circ$ .

Soluble with separation of gelatinous silica in boiling HCl or  $\text{H}_2\text{SO}_4$ .

Pennine, when optically (-), separated by optical character; when (+), by chemical test for  $\text{Al}_2\text{O}_3$ . It has lower birefringence.

Spodumene.— $\text{LiAlSi}_2\text{O}_6$ , H = 6.5-7.0, G = 3.1-3.2.

Monoclinic. (+).

Cleavage: (110), good; (010), (100), distinct. (110):(110) =  $93^\circ 12'$ .

Habit: Prisms; (100) tablets; (100) twinning.

Elongation: (110):(110), lath-shaped.

Orientation:  $b = \mathfrak{b}$ ,  $c : a = -23^\circ$  to  $-26^\circ$ .

Colorless, greenish.

Generally non-pleochroic in thin sections.  $a = \text{amethyst}$ ,  $\mathfrak{b} = \text{amethyst}$ ,  $c = \text{colorless}$ .

$\alpha = 1.660$ ,  $\beta = 1.666$ ,  $\gamma = 1.676$ .

$\gamma - \alpha = 0.016$ ,  $\gamma - \beta = 0.010$ ,  $\beta - \alpha = 0.006$ .



Dispersion:  $\rho < \nu$ .

$2V = 54^\circ - 60^\circ$ .

Unaffected by acids.

One of the pyroxenes.

Other minerals, see Part II.

**Hedenbergite.**— $\text{CaFe}(\text{SiO}_3)_2$ ,  $H = 5.0 - 6.0$ ,  $G = 3.5 - 3.58$ .

Monoclinic. (+).

Cleavage: (110), good.  $(110):(1\bar{1}0) = 92^\circ 50'$ .

Habit: Grains, prisms.

Elongation:  $(110):(1\bar{1}0)$ , lath-shaped.

Orientation:  $b = \mathbf{h}$ ,  $c:\mathbf{r} = -44^\circ$ .

Green.

Pleochroism: Weak.

$\alpha = 1.732$ ,  $\beta = 1.737$ ,  $\gamma = 1.751$ .

$\gamma - \alpha = 0.019$ ,  $\gamma - \beta = 0.014$ ,  $\beta - \alpha = 0.005$ .

Dispersion: Weak,  $\rho > \nu$ .

$2V = 59^\circ 52'$ .

Unacted upon by acids.

Other pyroxenes, see Part II.

**Augite.**— $\text{CaMgSi}_2\text{O}_6$  with  $(\text{Mg}, \text{Fe})(\text{Al}, \text{Fe})_2\text{SiO}_6$ ,  $H = 5.0 - 6.0$   $G = 3.2 - 3.6$

Monoclinic. (+).

Cleavage: (110), good.  $(110):(1\bar{1}0) = 93^\circ$ .

Habit: Short prisms, grains, (100) twinning.

Elongation:  $(110):(1\bar{1}0)$ , lath-shaped.

Orientation:  $b = \mathbf{h}$ ,  $c:\mathbf{r} = -45^\circ$  to  $-55^\circ$ .

Green, brown, reddish, violet, rarely yellow, nearly colorless.

Pleochroism: Usually weak, varies.

$\alpha = 1.698$ ,  $\beta = 1.704$ ,  $\gamma = 1.723$ .

$\gamma - \alpha = 0.025$ ,  $\gamma - \beta = 0.019$ ,  $\beta - \alpha = 0.006$ .

Dispersion: Weak,  $\rho > \nu$ . Distinct dispersion of bisectrices.

$2V = 60^\circ$  ca.

Unacted upon by acids.

Other pyroxenes, see Part II.

Olivine has different orientation of interference figure.

**Wohlerite.**— $\text{Si}_{10}\text{Zr}_3\text{Nb}_2\text{O}_{42}\text{Fe}_3\text{Ca}_{10}\text{Na}_5$ ,  $H = 5.5 - 6.0$ ,  $G = 3.41 - 3.442$ .

Monoclinic. (+).

Cleavage: (010), poor.

Habit: Tablets, grains, twinning widespread.

Elongation: (100), lath-shaped, tabular.

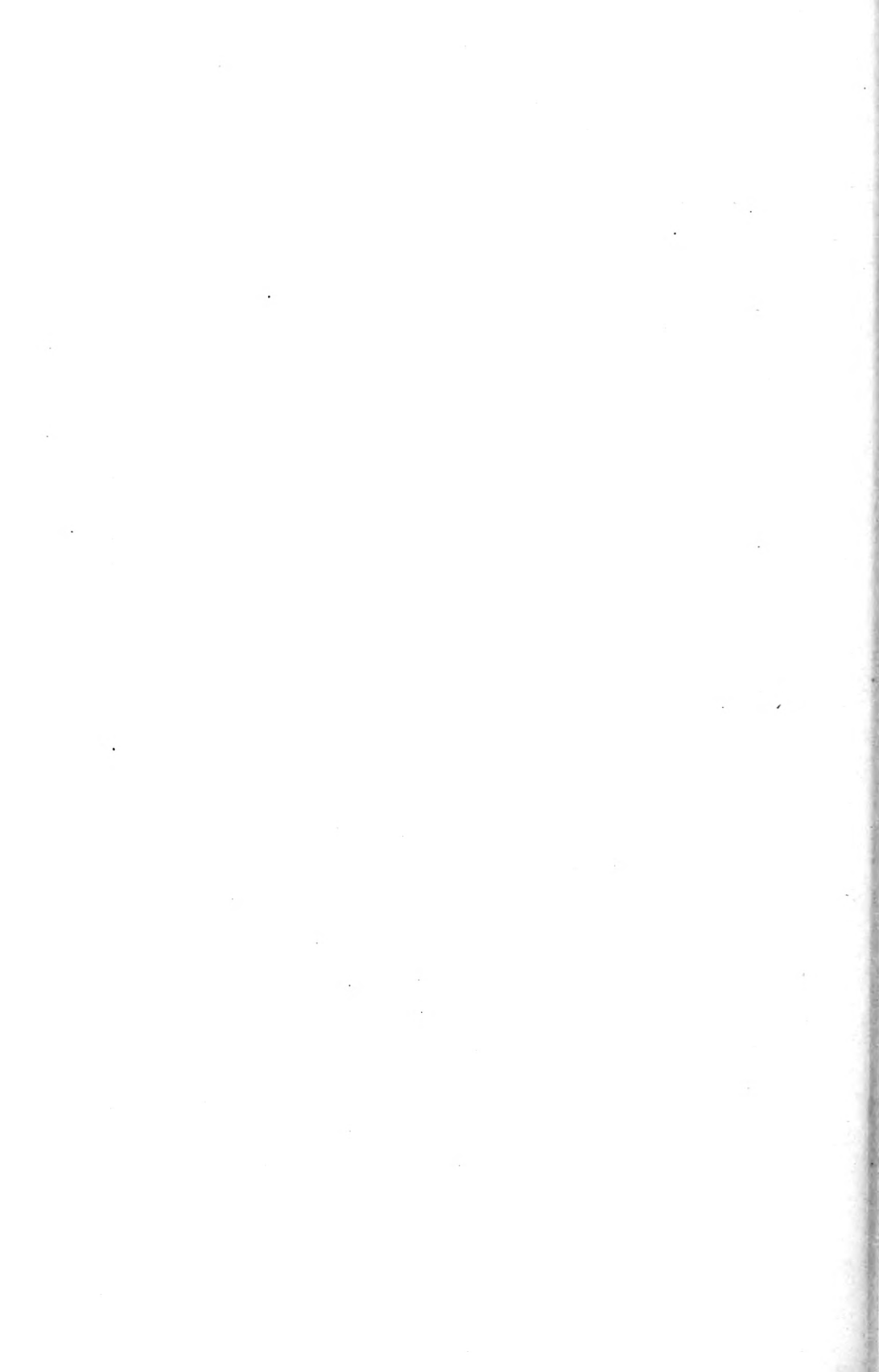
Orientation:  $b = \mathbf{a}$ ,  $c:\mathbf{r} = +44^\circ$ .

Yellow.

Pleochroism: Weak,  $\mathbf{r} > \mathbf{h} = \mathbf{a}$ .

$\alpha = 1.700$ ,  $\beta = 1.716$ ,  $\gamma = 1.726$ .

$\gamma - \alpha = 0.026$ ,  $\gamma - \beta = 0.010$ ,  $\alpha - \gamma = 0.016$ .



Dispersion: Weak,  $\rho < \nu$ .

$2V = 72^\circ - 77^\circ$

Easily soluble in HCl on warming.

**Lavenite** has higher double refraction and stronger pleochroism.

Polysynthetic twinning in wöhlerite.

**Jadeite.**—  $\text{NaAlSi}_2\text{O}_6$ ,  $H = 6.5 - 7.0$ ,  $G = 3.33 - 3.35$ .

Monoclinic. (+)

Cleavage: (110), good.  $(110):(110) = 93^\circ$ .

Habit: Short rod-like.

Elongation:  $(110):(110)$ , lath-shaped.

Orientation:  $b = \mathfrak{h}$ ,  $c : \mathfrak{c} = -33.5^\circ$ .

Colorless, light greenish.

Pleochroism: Wanting in thin sections.

$\beta = 1.654$ .

$\gamma - \alpha = 0.029$ .

Dispersion:  $\rho < \nu$ .

$2V = 72^\circ$ .

Unaffected by acids, even after fusion.

Other pyroxenes, see Part II.

**Diallage.**— Composition near diopside but often containing Al,  $H = 4.0$ ,  $G = 3.2 - 3.35$ .

Monoclinic. (+).

Cleavage: (110), (100), good.  $(110):(1\bar{1}0) = 92^\circ 50'$ .

Habit: Grains, short prisms, (100) twins frequent.

Elongation:  $(110):(1\bar{1}0)$ , lath-shaped.

Orientation:  $b = \mathfrak{h}$ ,  $c : \mathfrak{c} = -39^\circ$ .

Colorless, greenish, brownish.

Pleochroism: Weak,  $\mathfrak{h} = \text{yellowish}$ ,  $\mathfrak{a} = \mathfrak{c} = \text{greenish}$ .

Indices: Like diopside.

Birefringence: Like diopside.

Dispersion: Weak,  $\rho > \nu$ .

$2V = 59^\circ$  and less

Unacted upon by acids.

The complete (100) cleavage is most characteristic. Diallage is confined in occurrence to the gabbros, peridotites, and pyroxenites.

Other pyroxenes, see Part II.

Olivine has different orientation of interference figure.

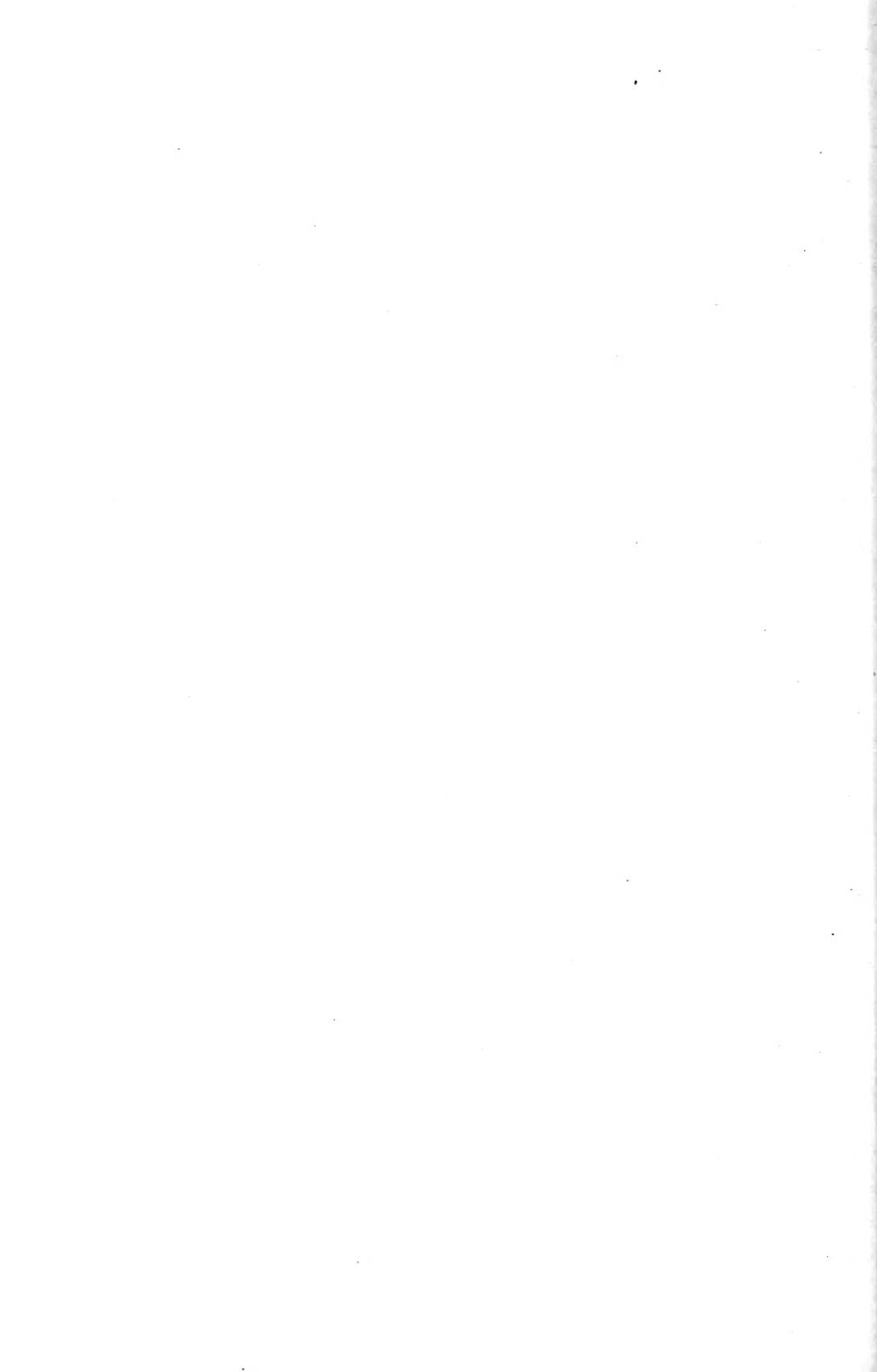
**Diopside.**—  $\text{CaMgSi}_2\text{O}_6$ ,  $H = 5.0 - 6.0$ ,  $G = 3.34$ .

Monoclinic. (+).

Cleavage: (110), good.  $(110):(110) = 92^\circ 50'$ .

Habit: Prismatic, grains, (100) twinning.

Elongation:  $(110):(110)$ , lath-shaped.





Orientation:  $b = \mathfrak{h}$ ,  $c : \epsilon = -39^\circ$ .

Colorless, greenish.

Pleochroism: Weak or wanting.

$\alpha = 1.671$ ,  $\beta = 1.678$ ,  $\gamma = 1.700$ .

$\gamma - \alpha = 0.029$ ,  $\gamma - \beta = 0.022$ ,  $\beta - \alpha = 0.007$ .

Dispersion: Weak,  $\rho > \nu$ .

$2V = 59^\circ$ .

Unacted upon by acids.

All pyroxenes are characterized by right-angled cleavage in basal sections. Zonal structure is common with increasing green color outward, and corresponding increase in the extinction angle.

Other pyroxenes, see Part II.

Olivine has different orientation of interference figure.

**Monazite.**— $(\text{Ce, La, Di})\text{PO}_4$ ,  $H = 5.5$ ,  $G = 4.9-5.3$ .

Monoclinic. (+).

Cleavage: (100), (010), distinct.

Habit: Tablets, often elongated on  $b$ .

Elongation: (001):(100), short laths. (—).

Orientation:  $b = a$ ,  $c : \epsilon = 2^\circ$  to  $6^\circ$ .

Colorless, yellowish.

Non-pleochroic in thin sections.

$\alpha = 1.796$ ,  $\beta = 1.797$ ,  $\gamma = 1.841$ .

$\gamma - \alpha = 0.045$ ,  $\gamma - \beta = 0.044$ ,  $\beta - \alpha = 0.001$ .

Dispersion: Weak,  $\rho < \nu$ .

$2E = 21^\circ$  to  $36^\circ$ .

Soluble with difficulty in  $\text{HCl}$ , leaving a white residue.

Olivine has  $2V = 88^\circ$  ca., and contains no P.

Titanite has strong dispersion  $\rho > \nu$ , and contains no P, extinction  $+39^\circ$ , weak pleochroism, and much higher birefringence.

**Astrophyllite.**— $\text{Ti, Fe, Mn, K}$  silicate.  $H = 3.0-4.0$ ,  $G = 3.3-3.4$ .

Orthorhombic. (+).

Cleavage: (100), good.

Habit: Plates, laths along  $b$ , leaves, rosettes.

Elongation: At right angles to (001), lath-shaped. ( $\pm$ ).

Orientation:  $a = a$ ,  $b = \epsilon$ .

Yellow.

Pleochroism:  $a = \text{yellow to red}$ ;  $\mathfrak{h} = \text{orange}$ ;  $\epsilon = \text{citron-yellow}$ .

$\alpha = 1.678$ ,  $\beta = 1.703$ ,  $\gamma = 1.733$ .

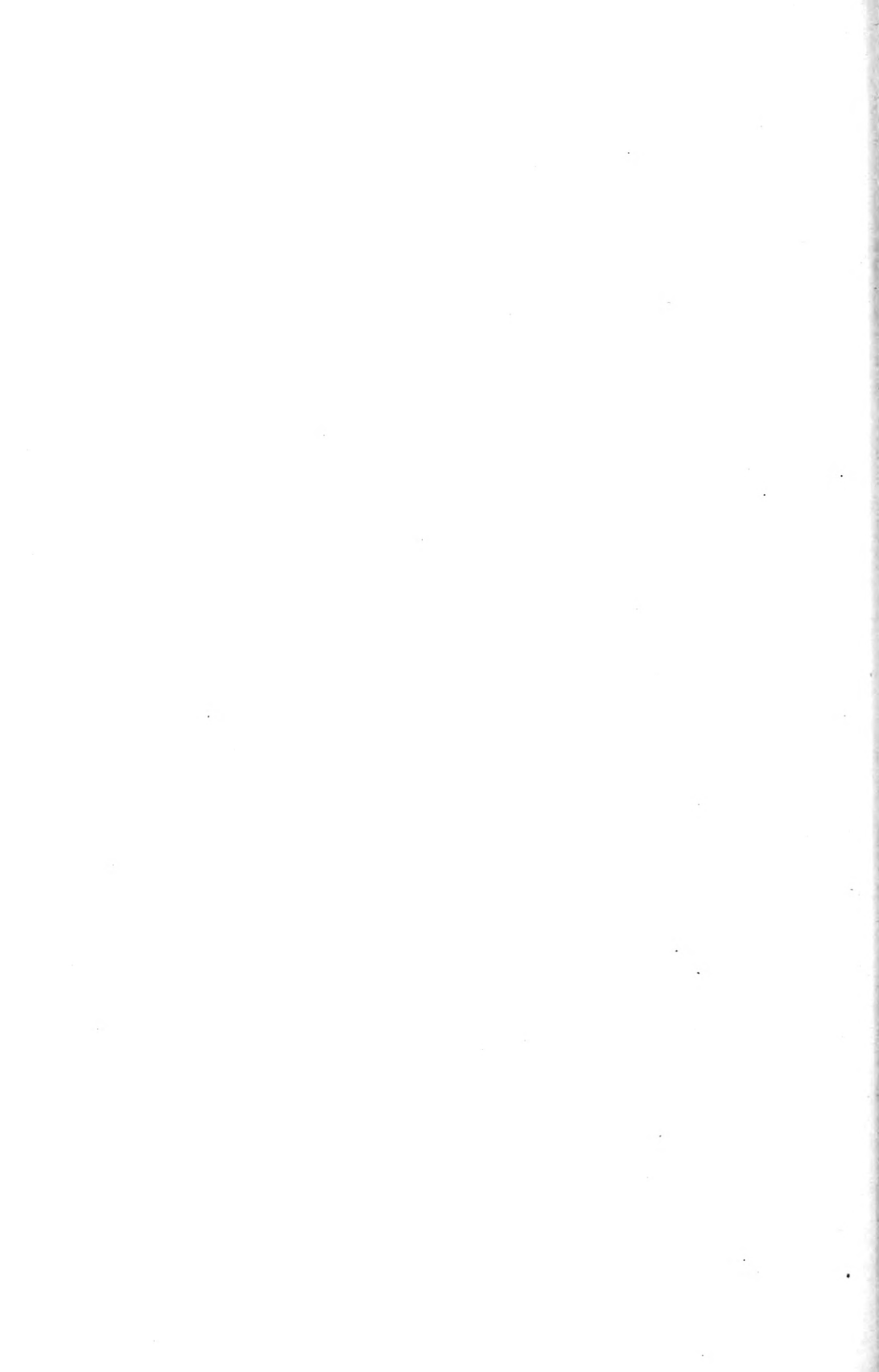
$\gamma - \alpha = 0.055$ ,  $\gamma - \beta = 0.030$ ,  $\beta - \alpha = 0.025$ .

Dispersion:  $\rho > \nu$ .

$2E = \text{ca. } 160^\circ$ .

Insoluble in  $\text{HCl}$ .

Micas have smaller axial angle and lower indices.



**Brittle Mic**as have lower double refraction, smaller axial angle around the bisectrix emerging on cleavage flakes, and are (-).

**Titanite.**—  $\text{CaSiTiO}_5$ ,  $H=5.0-5.5$ ,  $G=3.4-3.56$ .

Monoclinic. (+).

Cleavage: (110), distinct.  $(110):(110)=46^\circ 8'$ .

Habit: Prisms, rhombs, grains, rods.

Orientation:  $b=b$ ,  $c:c=+39^\circ$ .

Colorless, yellowish, reddish, brownish.

Pleochroism: Weak,  $c>b>a$ .

$\alpha=1.913$ ,  $\beta=1.921$ ,  $\gamma=2.054$ .

$\gamma-\alpha=0.147$ ,  $\gamma-\alpha=0.133$ ,  $\beta-\alpha=0.008$ .

Dispersion: Very strong,  $\rho>\nu$ .

$2E_{na}=45^\circ-68^\circ$ .

Very slightly affected by HCl.

**Monazite** has lower birefringence, weak dispersion, and low extinction angle.

**Brookite** has parallel extinction,  $2V=0^\circ$  to  $23^\circ$ , and great difference in birefringence in two directions;  $\gamma-\alpha=0.158$  while  $\beta-\alpha=0.003$ .

**Rutile**, **xenotime**, **hussakite**, and **cassiterite** give no Ca reactions.

*Cut on line.*



The mineral is **anisotropic**.

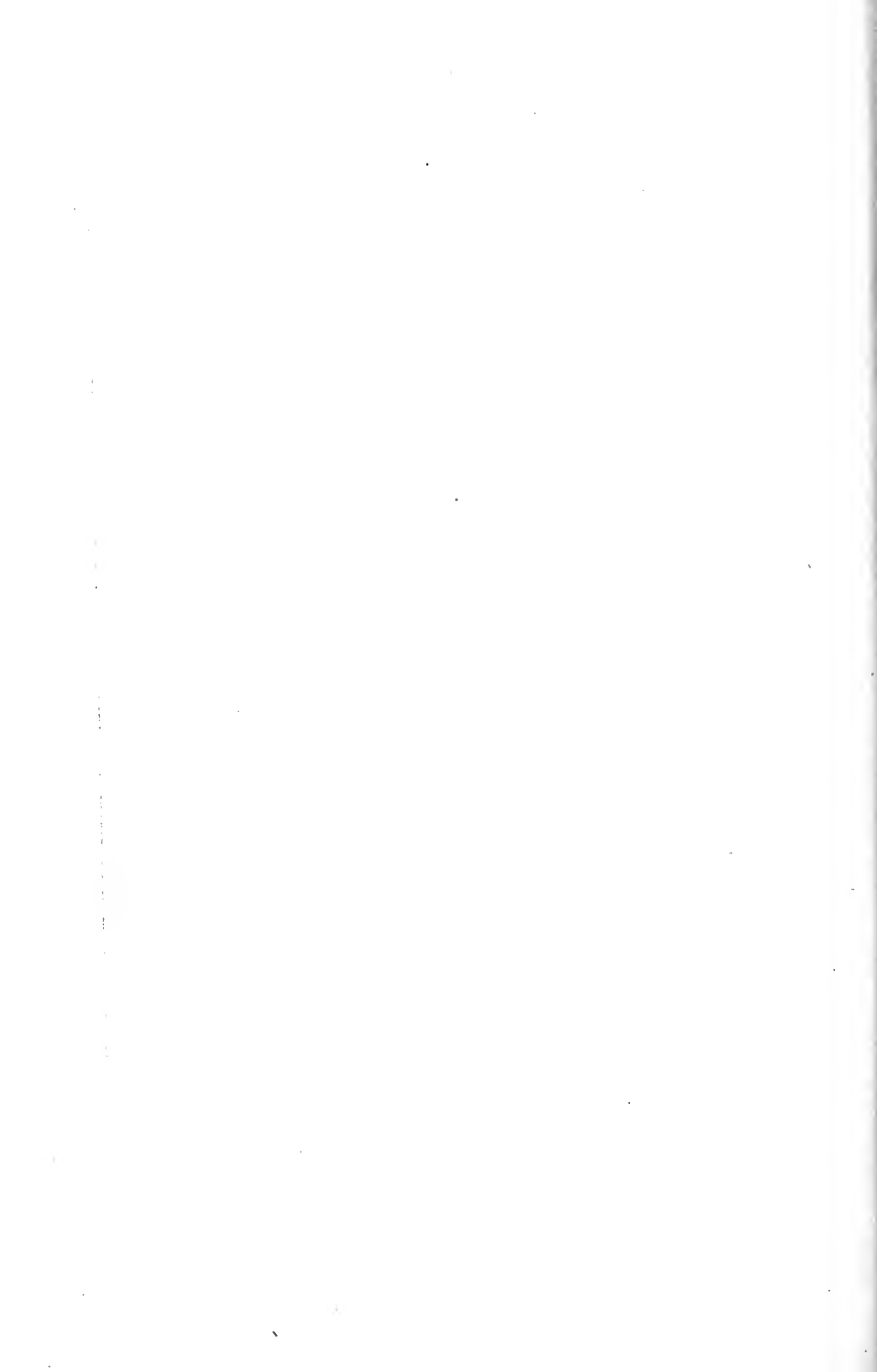
**Inclined extinction.**

**Colored.**

**Pleochroic.**

**PLEOCHROIC.**

*Cut on line.*



The mineral is anisotropic.

Inclined extinction.

Colored.

Pleochroic.

Maximum birefringence is less  
than that of quartz.

BIREFRINGENCE < QUARTZ.

*Cut on line.*





Thuringite.— $\text{H}_{18}\text{Fe}_8(\text{AlFe})_8\text{Si}_6\text{O}_{41}$ ,  $H=2.5$ ,  $G=3.15-3.19$ .

Monoclinic. (—).

Cleavage: (001), good.

Habit. Scales, irregular or concentric scaly aggregates.

Elongation: At right angles to (001), lath-shaped. (+).

Orientation:  $c:a=0^\circ$ .

Green, yellow.

Pleochroism:  $a$ =yellow;  $b=c$ =green.

Index similar to pennine, 1.583.

Birefringence similar to pennine, 0.002.

$2E=0^\circ-25^\circ$  ea.

A lepto-chlorite.

Gelatinizes easily with  $\text{HCl}$ .

Arfvedsonite.— $\text{Na}_2\text{Fe}_2\text{Si}_4\text{O}_{17}$ ,  $H=5.5-6.0$ ,  $G=3.44-3.46$ .

Monoclinic. (±).

Cleavage: (110), good; (100), distinct; (010), poor. (110):(110) =  $56^\circ 5'$ .

Habit: Short prisms, grains.

Elongation: (110):(110), lath-shaped. (—).

Orientation:  $b=b$ ,  $c:a=-70^\circ$  to  $-80^\circ$ .

Blue, brownish green, grayish green, grayish violet.

Pleochroism: Changeable, with  $a>b>c$ .

Index: High.

Birefringence: Very low.

Dispersion: Strong, of bisectrices;  $c:a_\beta<c:a_\alpha$ .

$2V$ =large.

Optical character probably (+) according to Brögger.

Unacted upon by acids.

**Glaucophane** has (+) elongation and smaller extinction angle.

**Riebeckite** has smaller extinction angle.

**Crossite** has  $a<c$ , and plane of optic axes is at right angles to that of arfvedsonite.

**Other minerals** than amphiboles, by cleavage.

**Amphiboles and pyroxenes**, see Part II.

Sapphirine.— $\text{Mg}_5\text{Al}_{12}\text{Si}_2\text{O}_{27}$ ,  $H=7.5$ ,  $G=3.486$ .

Monoclinic. (—).

Cleavage: Not seen.

Habit: Tablets, rods, grains.

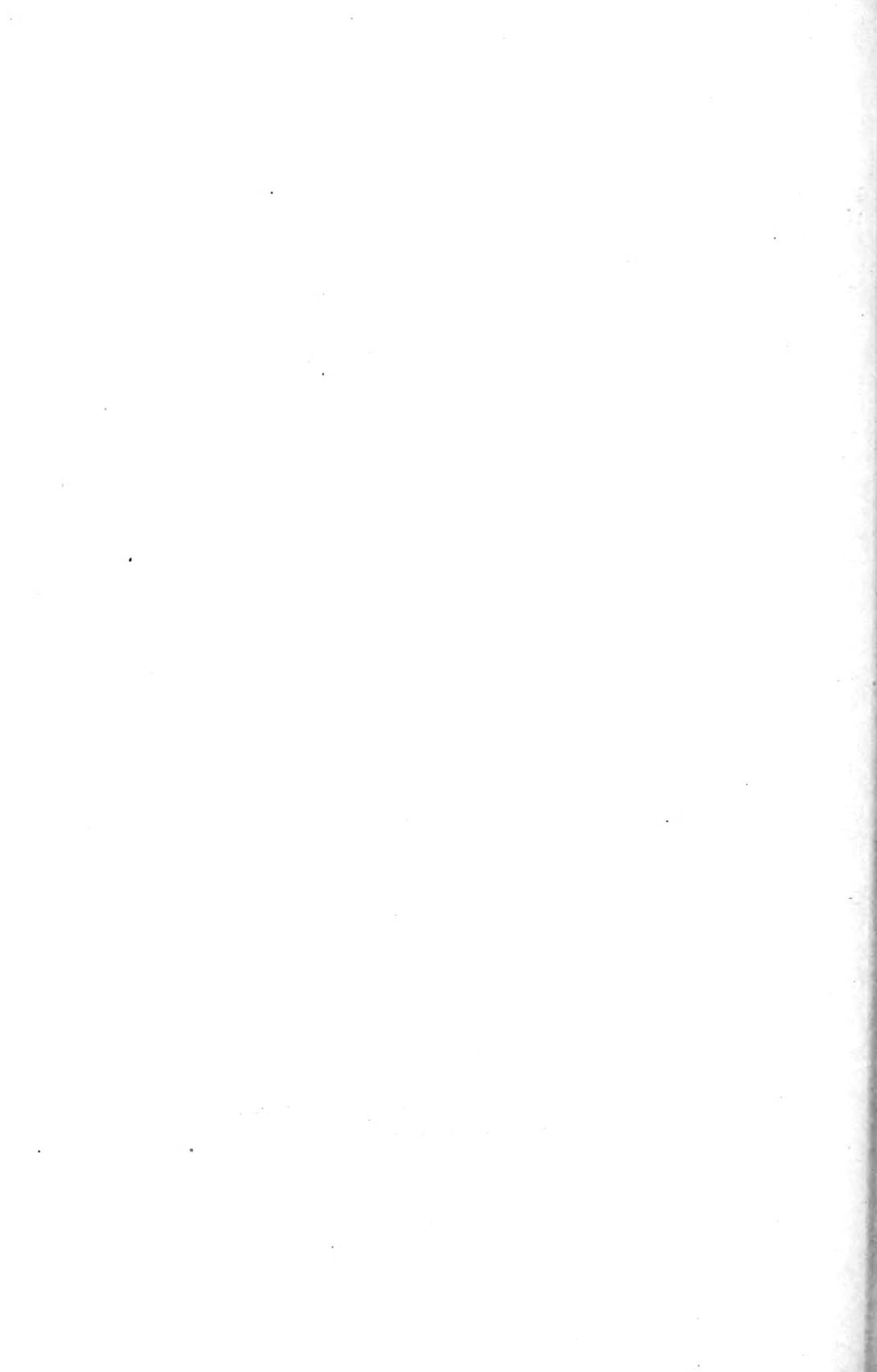
Elongation: (110):(110), lath-shaped. (+).

Orientation:  $b=b$ ,  $c:\epsilon=+8^\circ$  to  $+9^\circ$ .

Bluish, greenish, colorless.

Pleochroism:  $a$ =colorless,  $b=c$ =blue; or  $a$ =light greenish blue;  $b$ =dark blue-green;  $c$ =yellowish green.

Cut on line.



$\alpha = 1.706$ ,  $\beta = 1.709$ ,  $\gamma = 1.711$ .

$\gamma - \alpha = 0.005$ ,  $\gamma - \beta = 0.002$ ,  $\beta - \alpha = 0.003$ .

Dispersion: Distinct,  $\rho < \nu$ .

$2V = 69^\circ$ .

Insoluble in acids.

**Corundum** is uniaxial and has parallel extinction.

**Lazulite** has higher double refraction,  $\gamma - \alpha = 0.036$ .

**Cyanite**, brittle micas, and blue amphibole show cleavage lines.

**Blue cordierite** has lower indices of refraction,  $\alpha = 1.535$ .

**Serendibite** has polysynthetic twinning.

**Delessite.**— $H_{10}(Mg, Fe)_4(Al, Fe)_4Si_4O_{21}$ ,  $H = 2.5$ ,  $G = 2.5-3.0$ .

Monoclinic. (—).

Cleavage: (001), good.

Habit: Scales, spherulitic aggregates.

Elongation: At right angles to (001), lath-shaped. (+).

Orientation:  $b = \mathfrak{b}$ ,  $c: a$  = very small to  $0^\circ$ .

Green, yellow, brown.

Pleochroism:  $a$  = yellowish to colorless,  $\mathfrak{b}$  and  $\mathfrak{c}$  = green.

Indices: Similar to clinocllore, where  $\alpha = 1.585$ ,  $\beta = 1.586$ ,  $\gamma = 1.596$

Birefringence: Similar to clinocllore, where  $\gamma - \alpha = 0.011$ ,  $\gamma - \beta = 0.010$ ,  $\beta - \alpha = 0.001$ .

A lepto-chlorite.

Gelatinizes easily with acids.

**Clinocllore** is (+).

**Other minerals:** The resemblance of delessite to chlorite separates it from other minerals.

**Antigorite.**— $H_4(Mg, Fe)Si_2O_9$ ,  $H = 2.5$ ,  $G = 2.622$ .

Orthorhombic. (—).

Habit: Lamellæ, leaves, scales.

Elongation: At right angles to (100), lath-shaped. (+).

Orientation:  $a = \mathfrak{a}$ ,  $b = \mathfrak{c}$ .

Greenish, colorless, yellowish.

Non-pleochroic.

$\alpha = 1.560$ ,  $\beta = 1.570$ ,  $\gamma = 1.571$ .

$\gamma - \alpha = 0.011$ ,  $\gamma - \beta = 0.001$ ,  $\beta - \alpha = 0.010$ .

Dispersion:  $\rho > \nu$ .

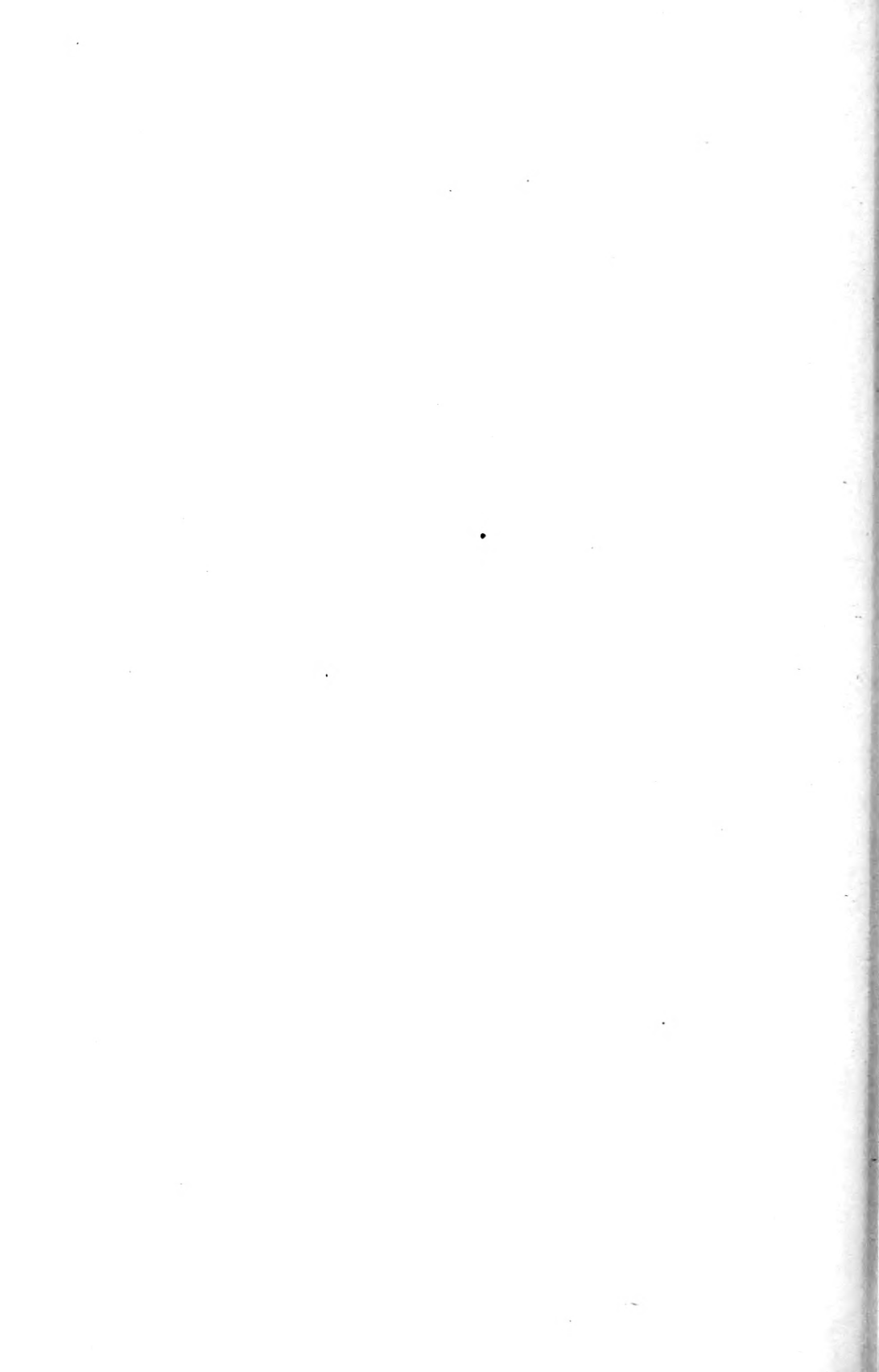
$2E = 16^\circ$  to  $98^\circ$ .

Silica separates in boiling HCl.

**Pennine** is pleochroic, has lower double and higher indices of refraction.

**Ordinary serpentine** is (+).

Cut on line.



**Pennine.**— A magnesium aluminium silicate.  $H=2.0-2.5$ ,  $G=2.73$ .

Monoclinic. ( $\pm$ ).

Cleavage: (001), good.

Habit: Leaves, scales, leafy aggregates.

Elongation: At right angles to (001), lath-shaped. ( $\pm$ ).

Orientation:  $b=b$ ,  $c:c$  or  $a=0^\circ$ .

Green.

Pleochroism:  $b$  and  $a$ =green;  $c$ =yellowish.

$\alpha=1.582$ ,  $\beta=(\quad)$ ,  $\gamma=1.584$ .

$\gamma-\alpha=0.002$ .

Dispersion:  $\rho > \nu$ , or  $\rho < \nu$ .

$2E=0^\circ$  to  $61^\circ$ .

Partially decomposed by HCl.

Often abnormal interference colors.

Micas have higher double refraction and different pleochroism.

Brittle micas have different pleochroism.

Other minerals do not have the scale-like character.

Serpentine has higher birefringence and lower indices.

The separation from antigorite may be difficult and is sometimes only possible chemically. Serpentine is usually much less pleochroic.

See also Part II.

**Rinkite.**— An iron-bearing titanosilicate of Ca, Ce, and Na.  $H=5.0$ ,  $G=3.46-3.50$ .

Monoclinic. (+).

Cleavage: (100), good.

Habit: Tablets, (100); (100) twinning frequent.

Elongation: (100):(010), lath-shaped. ( $\mp$ ).

Orientation:  $b=a$ ,  $c:b=7^\circ$  ea.

Yellowish, colorless.

Pleochroism:  $r > b > a$ .

$\alpha=1.665$ ,  $\beta=1.668$ ,  $\gamma=(\quad)$ .

$\beta-\alpha=0.003$ .

Dispersion: Strong,  $\rho < \nu$ .

$2E=78^\circ-82.5^\circ$ .

Easily soluble in HCl with separation of  $SiO_2$ .

Mosandrite has  $b=b$ ;  $c:a=3^\circ$ ; also strong  $\rho > \nu$ .

**Riebeckite**— $Na_2Fe_2Si_4O_{12}$ ,  $H=5.5-6.0$ ,  $G>3.33$ .

Monoclinic. ( $\pm$ ).

Cleavage: (110), good; (100), distinct; (010), poor. (110):(110) =  $56^\circ 0'$ .

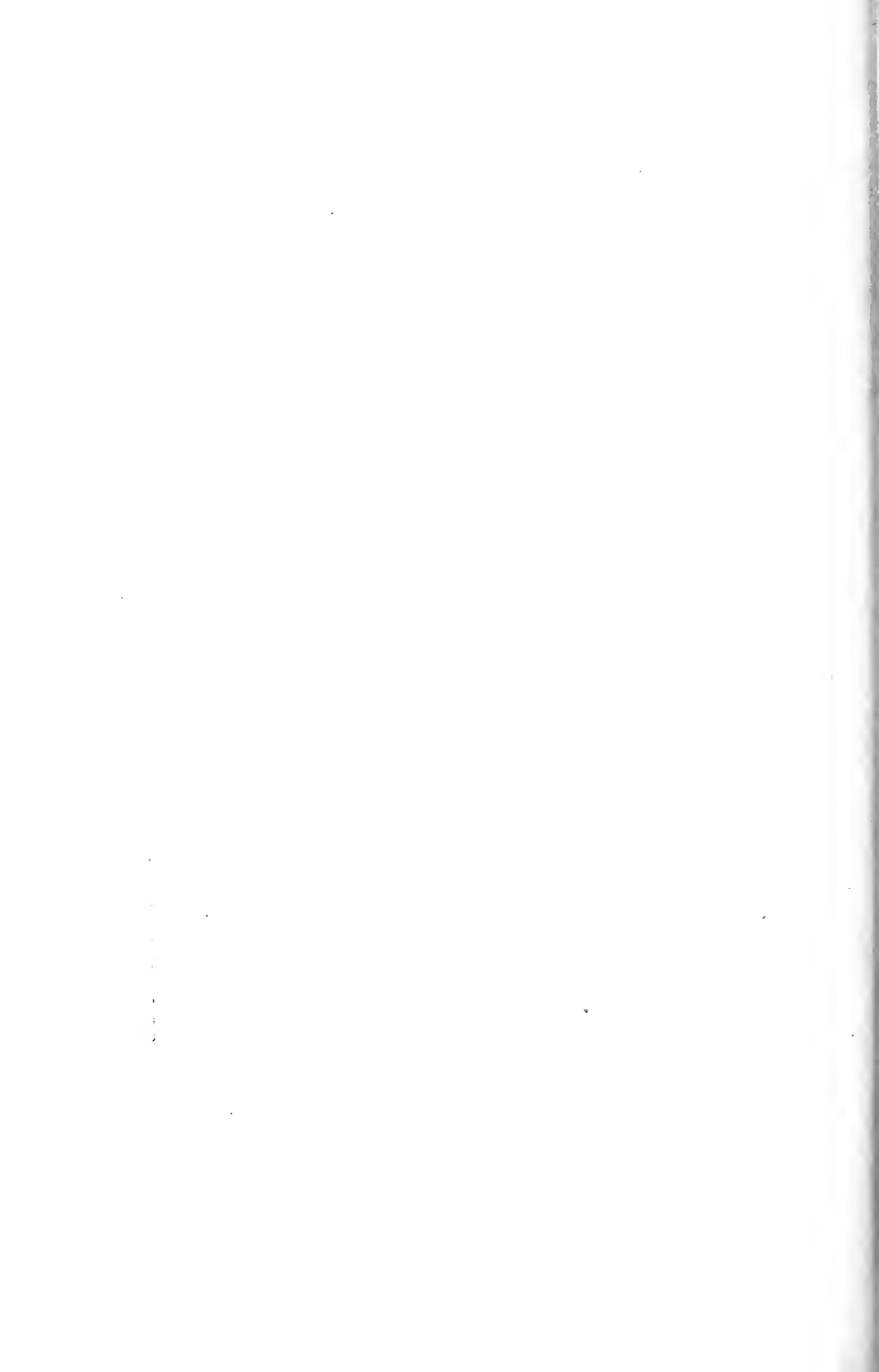
Habit: Short prisms, grains.

Elongation: (110):(110), lath-shaped. (—).

Orientation:  $b=b$ ,  $c:r=-85^\circ$ .

Blue, yellowish, green.

Cut on line.



Pleochroism: **a**=deep blue; **b**=lighter blue; **c**=yellowish green.  
 $\alpha > 1.687$ ,  $\gamma < 1.687$ .

$\gamma - \alpha = 0.004$ .

Dispersion: Strong,  $\rho > \nu$ .

Fuses easily and colors the flame an intense yellow.

**Other amphiboles**, see Part II.

See also arfvedsonite, above.

**Enigmatite**.— $\text{Na}_4\text{Fe}_9\text{AlFe}(\text{Si}, \text{Ti})_{12}\text{O}_{38}$ ,  $H = 5.5$ ,  $G = 3.80-3.86$ .

Triclinic. (+).

Cleavage: (110), (110), good.  $\angle 66^\circ$ .

Elongation: (110):(110), lath-shaped ( $\pm$ ).

Orientation: Extinction from cleavage on (100)=about  $3^\circ$  to  $6^\circ$ ; on (010), about  $44^\circ$ ; on (110) and (110) about  $30^\circ$  and  $37^\circ$ .

Brownish red.

Pleochroism: **a**=light red-brown; **b**=chestnut brown; **c**=brownish black.

Index: High, about like hornblende.

$\gamma - \alpha = 0.006$ .

Dispersion:  $\rho < \nu$ .

$2E = 60^\circ$  ea.

Somewhat acted upon by HCl.

**Other minerals**. The very low double and high index of refraction, the almost complete absorption of all but the red rays, and the good cleavage, are combined in no other minerals.

**Clinochlore**.—Hydrous magnesium, iron, aluminium silicate.  $H = 2.0-2.5$ ,  $G = 2.71$ .

Monoclinic. (+).

Cleavage: (001), good.

Habit: Leaves, scales, leafy aggregates. Twinning widespread.

Elongation: At right angles to (001), lath-shaped. (-).

Orientation:  $b = \mathbf{b}$ ,  $c : \mathbf{c} = -2^\circ$  to  $-9^\circ$ .

Green.

Pleochroism: **a** and **b**=green, **c**=yellow.

$\alpha = 1.585$ ,  $\beta = 1.586$ ,  $\gamma = 1.596$ .

$\gamma - \alpha = 0.011$ ,  $\gamma - \beta = 0.010$ ,  $\beta - \alpha = 0.001$ .

Dispersion:  $\rho < \nu$ .

$2E = 32^\circ$  to  $90^\circ$ .

One of the chlorite group.

**Micas** have higher birefringence and stronger or no pleochroism.

**Serpentine** may sometimes be difficult to separate from clinochlore.

**Pennine** is ( $\pm$ ),  $2E = 0^\circ-61^\circ$ ,  $c : \mathbf{c} = 0^\circ$ ,  $\gamma - \alpha = 0.002$ .

**Other minerals**. Chlorite has very low double refraction.

Cut on line.





The mineral is **anisotropic**.

**Inclined** extinction.

**Colored**.

**Pleochroic**.

**Maximum birefringence** is greater  
than that of quartz.

BIREFRINGENCE > QUARTZ.

*Cut on line.*



**Antigorite.**— $H_4(Mg, Fe)_3Si_2O_{10}$ ,  $H = 2.5$ ,  $G = 2.622$ .

Orthorhombic. (—).

Habit: Lamellæ, leaves, scales.

Elongation: At right angles to (100), lath-shaped. (+).

Orientation:  $a = n$ ,  $b = r$ .

Greenish, colorless, yellowish.

Non-pleochroic.

$\alpha = 1.560$ ,  $\beta = 1.570$ ,  $\gamma = 1.571$ .

$\gamma - \alpha = 0.011$ ,  $\gamma - \beta = 0.001$ ,  $\beta - \alpha = 0.010$ .

Dispersion:  $\rho > \nu$ .

$2E = 16^\circ$  to  $98^\circ$ .

Silica separates in boiling HCl.

**Pennine** is pleochroic, has lower double and higher indices of refraction

**Ordinary serpentine** is (+).

**Disthene.**— $Al_2SiO_5$ ,  $H = 4.0-7.0$ ,  $G = 3.56-3.67$ .

Triclinic. (—).

Cleavage: (100), good; (010), distinct. (100):(010) =  $74^\circ$ .

Habit: Prisms, tablets.

Elongation: (100):(010), lath-shaped. (+).

Orientation:  $n$  = nearly at right angles to (100);  $r$  = inclined  $30^\circ$  on (100) against the (100):(010) edge.

Colorless, blue.

Pleochroism: Weak, between blue and colorless.

$\alpha = 1.717$ ,  $\beta = 1.722$ ,  $\gamma = 1.729$ .

$\gamma - \alpha = 0.012$ ,  $\gamma - \beta = 0.007$ ,  $\beta - \alpha = 0.005$ .

Dispersion:  $\rho > \nu$ .

$2V = 82^\circ$ .

Does not occur in eruptive rocks, but in crystalline schists and gneisses.

Insoluble in acids.

**Sillimanite** and **andalusite** are orthorhombic, have parallel extinction, and different cleavage.

**Topaz** has basal cleavage and is orthorhombic.

**Zoisite** and **colorless epidote** have different position of axial plane in relation to cleavage.

**Serendibite** and **dumortierite** have different pleochroism.

**Blue amphibole** has different cleavage and lower indices of refraction.

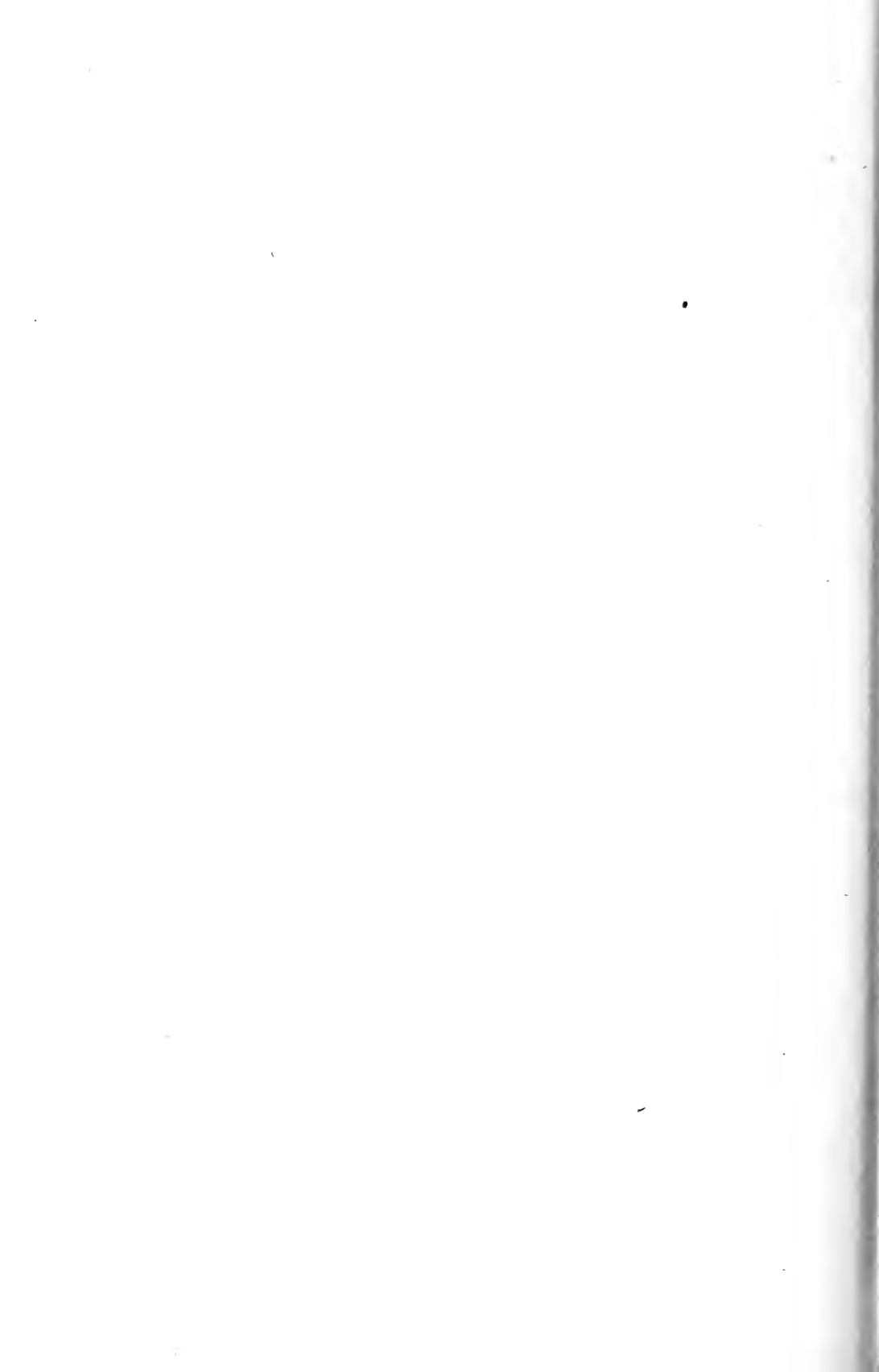
**Bastite.**—Serpentine pseudomorph after an orthorhombic pyroxene.

$H = 3.5-4.0$ ,  $G = 2.6-2.8$ .

Orthorhombic. (—).

Cleavage: (100), good.

Habit: Leaves.



Elongation: (110), (1 $\bar{1}$ 0), lath-shaped. (+).

Orientation:  $a = \mathfrak{a}$ ,  $c = \mathfrak{c}$ .

Greenish, yellowish, colorless.

Pleochroism: Weak or wanting.

Index: 1.5–1.6.

Birefringence: Weak.

Dispersion:  $\rho > \nu$ .

$2E = 20^\circ$ – $90^\circ$ .

Gelatinizes more or less easily with acids.

Other pyroxenes differ in orientation. See Part II.

**Hornblende**, Common.—Ca, Mg, Fe silicate.  $H = 5.0$ – $6.0$ ,  $G = 2.9$ – $3.1$ .

Monoelinic. ( $\mp$ ).

Cleavage: (110), good; (100), distinct; (010), poor. (110):(1 $\bar{1}$ 0) =  $55.5^\circ$ .

Habit: Prisms, rods, grains.

Elongation: (110):(1 $\bar{1}$ 0), lath-shaped. (+).

Orientation:  $b = \mathfrak{b}$ ,  $c : \mathfrak{c} = -12^\circ$  to  $-20^\circ$ .

Green, rarely brown.

Pleochroism: In green and yellow tones with  $\mathfrak{c} > \mathfrak{b} > \mathfrak{a}$ .

$\alpha = 1.640$ ,  $\beta = 1.643$ ,  $\gamma = 1.656$ .

$\gamma - \alpha = 0.016$ ,  $\gamma - \beta = 0.013$ ,  $\beta - \alpha = 0.003$ .

$2V = 54^\circ$  to  $84^\circ$ .

Insoluble in acids.

Arfvedsonite has (–) elongation.

Other amphiboles, see Part II.

**Glaucophane**.— $\text{NaAl}(\text{SiO}_3)_2 \cdot (\text{Fe}, \text{Mg})\text{SiO}_3$ ,  $H = 6.0$ – $6.5$ ,  $G = 3.103$ – $3.113$ .

Monoelinic. (–).

Cleavage: (110), good; (100), distinct; (010), poor. (110):(1 $\bar{1}$ 0) =  $55^\circ 16'$ .

Habit: Short prisms, grains. (100) twinning.

Elongation: (110):(1 $\bar{1}$ 0), lath-shaped. (+).

Orientation:  $b = \mathfrak{b}$ ,  $c : \mathfrak{c} = -4^\circ$  to  $-6^\circ$ .

Blue, violet, yellowish green, almost colorless.

Pleochroism:  $\mathfrak{a}$  = nearly colorless to yellowish green,  $\mathfrak{b}$  = reddish to bluish violet,  $\mathfrak{c}$  = blue.

$\alpha = 1.621$ ,  $\beta = 1.638$ ,  $\gamma = 1.639$ .

$\gamma - \alpha = 0.018$ ,  $\gamma - \beta = 0.001$ ,  $\beta - \alpha = 0.017$ .

Dispersion: Strong.

$2E = 85.5^\circ$ ,  $2V_{na} = 43^\circ 58'$ .

One of the amphiboles.

But slightly affected by acids.

Other minerals which resemble it differ in cleavage, pleochroism, and have (–) elongation.

Cut on line.



**Carpholite.**— $\text{H}_4\text{MnAl}_2\text{Si}_2\text{O}_{10}$ ,  $H = 5.0-5.5$ ,  $G = 2.935$ .

Monoclinic. (—).

Cleavage: Unnoticeable.

Habit: Rods, fibres.

Elongation:  $(110):(1\bar{1}0)$ , narrow laths. (+).

Orientation:  $b = a$ ,  $c : \epsilon = 4^\circ$  ca.

Colorless, greenish yellow.

Pleochroism: Distinct:  $\epsilon$  = colorless;  $a = b$  = yellowish green.

Index:  $n = 1.627$ .

$\gamma - \alpha = 0.022$ .

$2V = 60^\circ$ .

Insoluble in acids.

**Rosenbuschite** is soluble in acids, has (—) elongation,

$2V = 90^\circ$ , and cleavage (001), good.

**Sillimanite** is (+), non-pleochroic, cleavage (100) good.

**Rosenbuschite.**— $2\text{Na}_2\text{ZrO}_2\text{F}_2 \cdot 6\text{CaSiO}_3 \cdot \text{TiSiO}_3 \cdot \text{TiO}_3$ ,  $H = 5.0-6.0$ ,  $G = 3.30-3.315$ .

Monoclinic. ( $\pm ?$ ).

Cleavage: (001), good; (100), distinct.  $(001):(100) = 78^\circ$

Habit: Rods along  $b$ .

Elongation: Narrow laths. (—).

Orientation:  $b = a$ ,  $c : \epsilon = +13^\circ$ .

Colorless, light greenish yellow.

Pleochroism: Not marked,  $\epsilon > b > a$ .

Index:  $n = 1.65$  ca.

$\gamma - \alpha = 0.026$  ca.

$2V = \text{near } 90^\circ$ .

Easily attacked by HCl.

**Sillimanite** and **carpholite** are not affected by HCl and have (+) elongation.

**Wollastonite** has ( $\pm$ ) elongation, lower double refraction and higher extinction angle.

**Pectolite** has (+) elongation.

**Actinolite.**— $\text{Ca}(\text{Fe}, \text{Mg})_3\text{Si}_4\text{O}_{12}$ ,  $H = 5.0-6.0$ ,  $G = 3.0-3.2$ .

Monoclinic. (—).

Cleavage: (110), good; (100), distinct; (010), poor.  $(110):(1\bar{1}0) = 55^\circ 49'$ .

Habit: Rods, leaves, grains. Twinning (100) occurs.

Elongation:  $(110):(1\bar{1}0)$ , lath-shaped. (+).

Orientation:  $b = b$ ,  $c : \epsilon = -15^\circ$ .

Green.

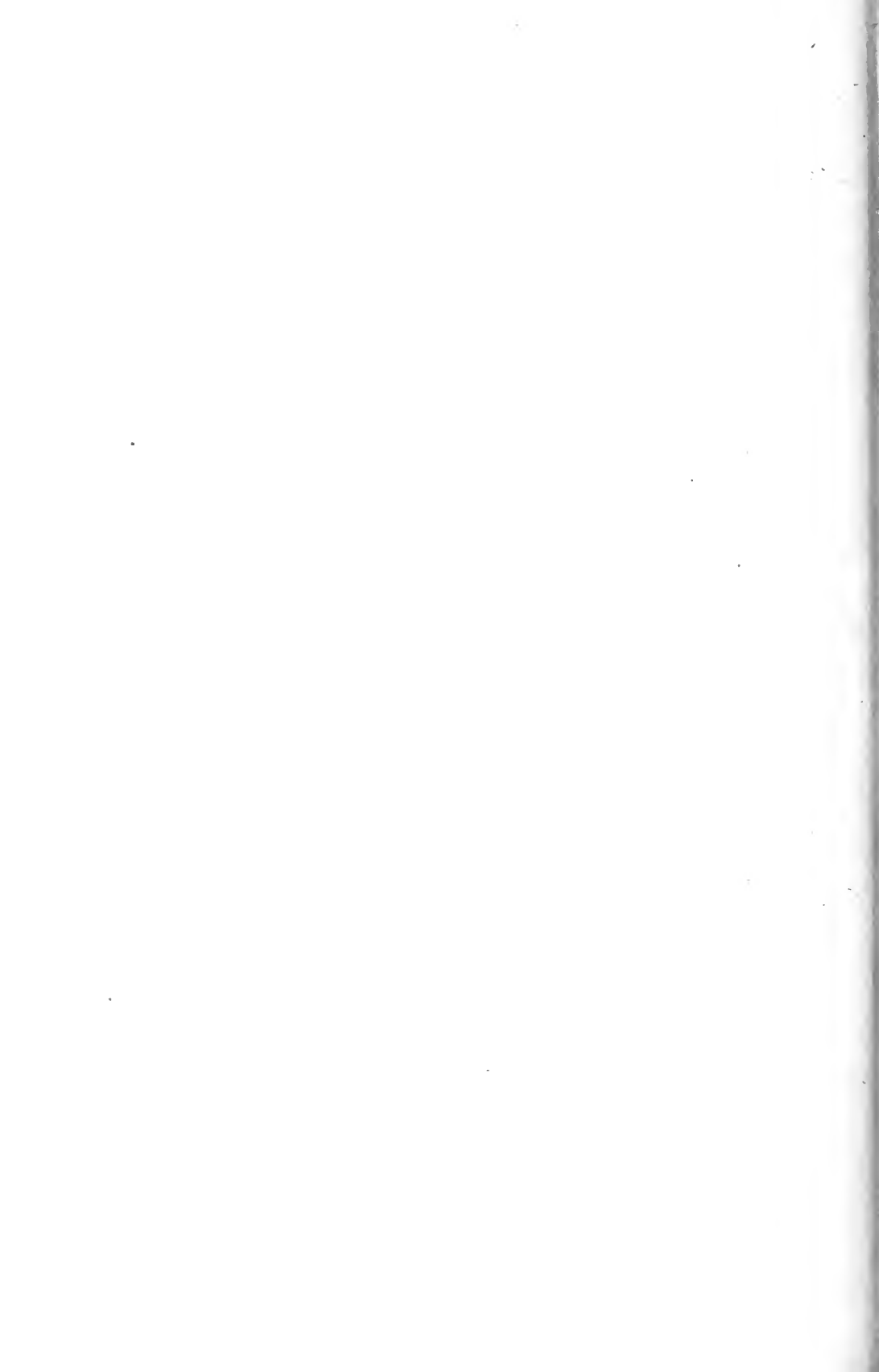
Pleochroism: Hardly noticeable in thin sections.  $\epsilon$  = green;

$b$  and  $a$  = yellowish green.

$\alpha = 1.607$ ,  $\beta = 1.624$ ,  $\gamma = 1.634$ .

$\gamma - \alpha = 0.027$ ,  $\gamma - \beta = 0.010$ ,  $\beta - \alpha = 0.017$ .

Dispersion: Weak,  $\rho < \nu$ .





$2V = 80^\circ$  to  $81.5^\circ$ .

But slightly acted upon by HCl.

**Pistacite** has trace of the plane of the optic axes at right angles to the cleavage, and  $(\pm)$  elongation.

**Pyroxenes** differ in cleavage and have higher extinction angles. See Part II.

**Pistacite.**—(Epidote).  $\text{Al}(\text{SiO}_4)_3(\text{Al}, \text{Fe})_2\text{Ca} \cdot \text{CaOH}$ ,  $H = 6.5$ ,  $G = 3.3-3.5$ .  
Monoclinic.  $(-)$ .

Cleavage: (001), good; (100), distinct;  $(001):(100) = 64^\circ 37'$ .

Habit: Prisms, and rods elongated along  $b$ , grains. Twinning (100) occurs.

Elongation:  $(001):(100)$ , lath-shaped.  $(\pm)$ .

Orientation:  $b = \mathbf{b}$ ,  $c: \mathbf{a} = +3^\circ$ .

Green, yellow, brownish, colorless.

Pleochroism:  $\mathbf{a}$  = colorless to yellowish or greenish.  $\mathbf{b}$  = yellowish to yellowish gray, lavender;  $\mathbf{c}$  = green, light yellowish green.

$\alpha = 1.714$ ,  $\beta = 1.741$ ,  $\gamma = 1.746$ .

$\gamma - \alpha = 0.032$ ,  $\gamma - \beta = 0.005$ ,  $\beta - \alpha = 0.027$ .

Dispersion:  $\rho > \nu$ .

$2V = 74^\circ-90^\circ$ .

Not affected by HCl.

Pistacite is the Fe rich epidote; clinozoisite, the Fe poor or free epidote.

**Pyroxene** has (110) cleavage; in sections parallel to the long direction, the trace of the optic axes is parallel to the cleavage; in epidote at right angles.

**Clinozoisite** has lower double refraction, is  $(+)$ , and has strong  $\rho < \nu$  dispersion.

**Piedmontite.**— $\text{Al}(\text{SiO}_4)_3(\text{Al} \cdot \text{Mn} \cdot \text{Fe})_2\text{Ca} \cdot \text{CaOH}$ ,  $H = 6.5$ ,  $G = 3.40$ .  
Monoclinic.  $(-)$ . Mn-rich piedmontite is  $(+)$ .

Cleavage: (001), good; (100), distinct.  $(001):(101) = 63^\circ 30.5'$ .

Habit: Prisms, rods elongated along  $b$ , grains.

Elongation:  $(001):(100)$ , lath-shaped.  $(\pm)$ .

Orientation:  $b = \mathbf{b}$ ,  $c: \mathbf{a} = +5^\circ$  to  $+6^\circ$ .

Red, yellow, colorless.

Pleochroism: Strong and characteristic.  $\mathbf{a}$  = orange;  $\mathbf{b}$  = violet, amethyst;  $\mathbf{c}$  = red.

$\alpha = 1.714$ ,  $\beta = 1.741$ ,  $\gamma = 1.746$ .

$\gamma - \alpha = 0.032$ ,  $\gamma - \beta = 0.005$ ,  $\beta - \alpha = 0.027$ .

$2V = 90^\circ$ ; it becomes greater than  $90^\circ$  in the Mn-rich piedmontites, and the mineral becomes optically  $(+)$ .

A manganese epidote

Insoluble in HCl.

**Pistacite, clinozoisite, and orthite** have different pleochroism.

**Other minerals** are separated by the epidote-like character of piedmontite and by the pleochroism.



**Lazulite.**— $(\text{AlOH})_2\text{Mg}(\text{PO}_4)_2$ ,  $H = 5.0\text{--}6.0$ ,  $G = 3.00\text{--}3.12$ .

Monoclinic. (—).

Cleavage: Seldom seen microscopically.

Habit: Pyramids, grains.

Orientation:  $b = h$ ,  $c: a = -10^\circ$ .

Blue, colorless.

Pleochroism:  $a = \text{colorless}$ ,  $h = c = \text{sky-blue}$ .

$\alpha = 1.603$ ,  $\beta = 1.632$ ,  $\gamma = 1.639$ .

$\gamma - \alpha = 0.036$ ,  $\gamma - \beta = 0.007$ ,  $\beta - \alpha = 0.029$ .

Dispersion: Strong,  $\rho < \nu$ .

$2E = 135^\circ$  ca.

Unacted upon by acids.

**Corundum** is uniaxial, and has 0.009 as maximum birefringence.

**Blue cordierite** has 0.009 as maximum birefringence.

**Disthene** and **blue amphibole** have good cleavage.

**Dumortierite** has good (100) cleavage,  $2V = 30^\circ$ .

**Sapphirine** and **serendibite** have weak birefringence.

**Paragonite.**— $\text{Al}(\text{SiO}_4)_2\text{Al}_2\text{NaH}_2$ ,  $H = 2.0\text{--}2.5$ ,  $G = 2.8\text{--}2.9$ .

Monoclinic. (—).

Cleavage: (001), good.

Habit: Leaves, leafy aggregates.

Elongation: Perpendicular to (001), lath-shaped. (+).

Orientation:  $b = c$ ,  $c: a = 0^\circ$  to  $+2^\circ$ .

Colorless, greenish, yellowish.

Pleochroism: Weak or wanting.

Indices: Very similar to muscovite, in which  $\alpha = 1.563$ ,  $\beta = 1.598$ ,  $\gamma = 1.601$ .

Birefringence: Like muscovite, in which  $\gamma - \alpha = 0.038$ ,  $\gamma - \beta = 0.003$ ,  $\beta - \alpha = 0.035$ .

Dispersion: Weak,  $\rho > \nu$ .

$2E = 70^\circ$  ca.

Insoluble in acids.

One of the micas.

**Muscovite** and **lepidolite** are different chemically.

**Talc** has  $2E = 6^\circ$  to  $20^\circ$ .

See Part II.

**Lavenite.**— $(\text{SiO}_3)_2(\text{Mn}, \text{Ca}, \text{Fe})(\text{ZrO} \cdot \text{F})\text{Na}$ ,  $H = 6.0$ ,  $G = 3.51\text{--}3.547$ .

Monoclinic. (—).

Cleavage: (100), distinct.

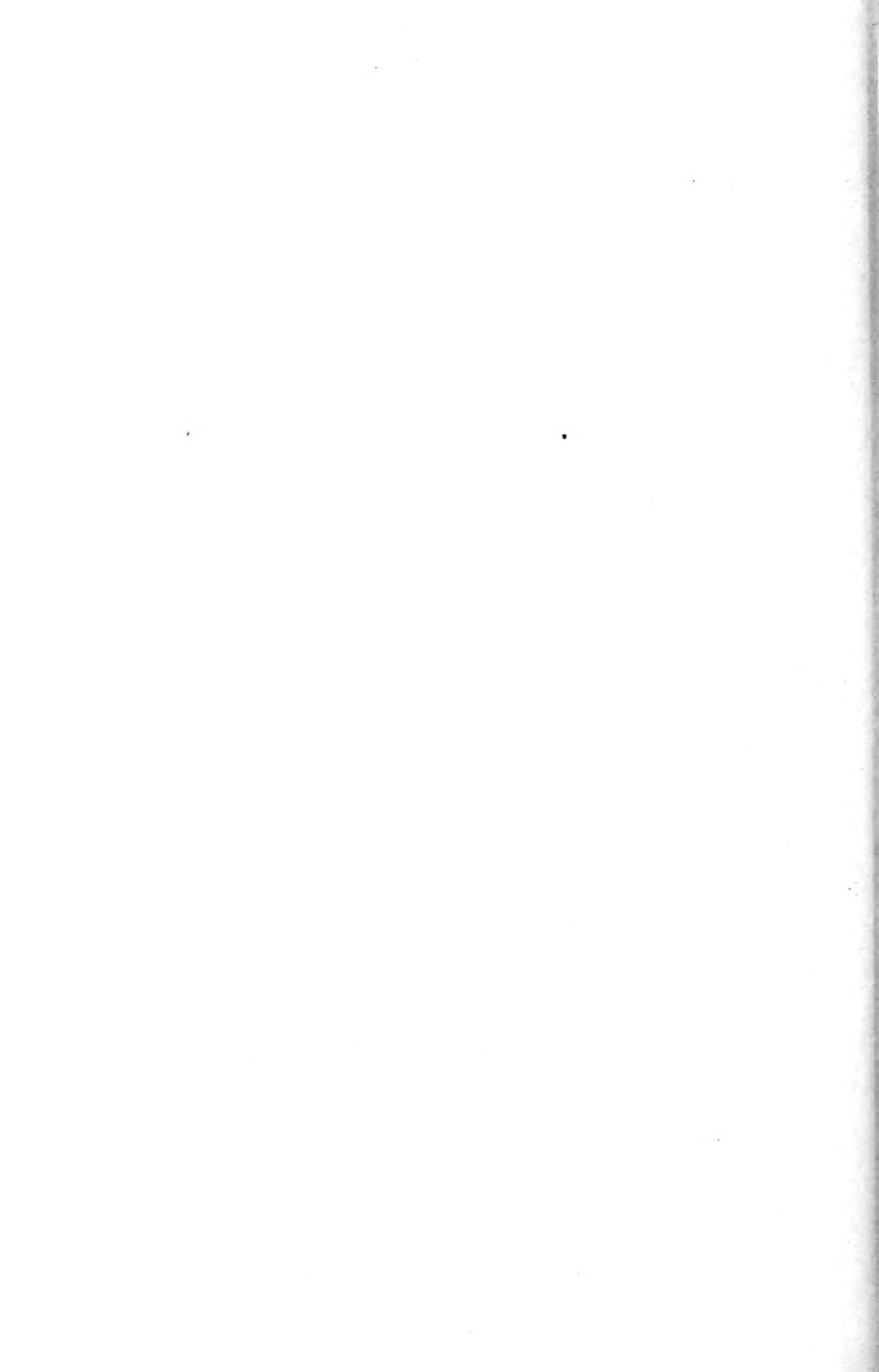
Habit: Prisms, grains.

Elongation: (110):(110), short laths. ( $\pm$ ).

Orientation:  $b = h$ ,  $c: a = +20^\circ$ .

Yellow.

Cut on line.



Pleochroism:  $\epsilon$  = orange to red-brown;  $\mathfrak{b}$  = yellowish;  $\mathfrak{a}$  = light yellow.

Index:  $n = 1.750$ .

Birefringence: 0.040.

Dispersion: Indistinct.

$2V = 80^\circ$ .

Wöhlerite usually occurs as tablets, has lower birefringence, weaker pleochroism, and polysynthetic twinning.

**Biotite.**—Mg, Fe, Al silicate.  $H = 2.5-3.0$ ,  $G = 2.8-3.2$ .

Monoclinic. Often appears uniaxial. (—).

Cleavage: (001), good.

Habit: leaves, leafy aggregates.

Elongation: At right angles to (001), lath-shaped. (+).

Orientation:  $b = \mathfrak{b}$ ,  $c : \mathfrak{a} = +0^\circ$  to  $+7^\circ$ .

Brown, green, yellow.

Pleochroism: Strong,  $\epsilon \gtrsim \mathfrak{b} > \mathfrak{a}$ .  $\epsilon$  and  $\mathfrak{b}$  = deep-brown to red-brown, deep-green to black;  $\mathfrak{a}$  = light yellow to red, light green.

$\alpha = 1.557$ ,  $\beta = 1.589$ ,  $\gamma = 1.597$ .

$\gamma - \alpha = 0.040$ ,  $\gamma - \beta = 0.008$ ,  $\beta - \alpha = 0.032$ .

Dispersion: Weak,  $\rho \gtrsim \nu$ .

$2E = 0^\circ$  to  $72^\circ$ .

Soluble in  $H_2SO_4$  and the Fe rich in HCl with separation of  $SiO_2$  scales.

Minerals other than micas, see Part II.

Alkali micas have different color, pleochroism, larger  $2V$ , different position of plane of the optic axes, and are different chemically.

Anomite has different position of the plane of the optic axes.

Lithionite, when dark in color, may be separated by the Li reaction.

**Anomite.**—Under anomite, following Rosenbusch, are included those rock-forming biotites which have the plane of the optic axes at right angles to the symmetry plane. See Part II.

$H = 2.5-3.0$ ,

$G = 2.8-3.2$ .

Monoclinic. (—).

Cleavage: Good, (001).

Habit: Leaves, leafy aggregates.

Elongation: At right angles to (001), lath-shaped. (+).

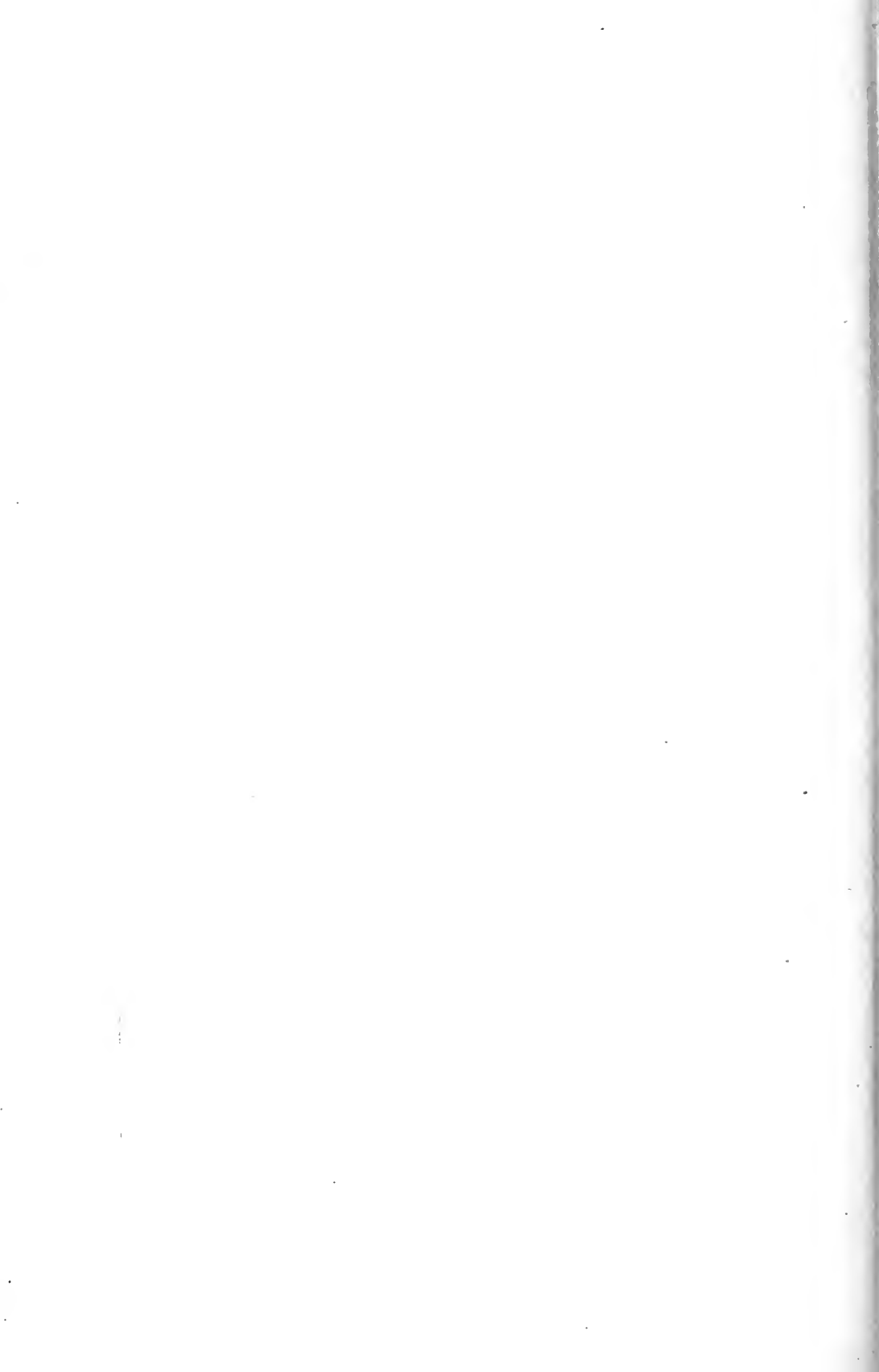
Orientation:  $b = \epsilon$ ,  $c : \mathfrak{a} = 0^\circ$  to  $+4^\circ$ .

Brown, green, yellow.

Pleochroism: Very strong, like biotite.  $\epsilon > \mathfrak{b} > \mathfrak{a}$ .

Indices: Like biotite.

Birefringence: Like biotite.



Dispersion: Weak,  $\rho \gtrsim \nu$ .

$2E = 10^\circ - 68^\circ$ .

Biotite has  $b = \mathfrak{b}$ .

Other micas, see biotite.

Other minerals than micas, see Part II.

**Zinnwaldite.**—K,Li,Fe,Al silicate.  $H = 2.5 - 3.0$ ,  $G = 2.82 - 3.20$ .

Monoclinic. (—).

Cleavage: (001), good.

Habit: Leaves, leafy aggregates.

Elongation: At right angles to (001), lath-shaped. (+).

Orientation:  $b = \mathfrak{b}$ ,  $c: a = 0^\circ$  to  $+7^\circ$ .

Brown, red, yellow, rarely green.

Pleochroism: Strong,  $\mathfrak{r} > \mathfrak{b} > \mathfrak{a}$ .  $\mathfrak{r}$  and  $\mathfrak{a}$  = dark-brown, brownish gray;  $\mathfrak{b}$  = yellowish brown or reddish, nearly colorless.

Indices: Similar to biotite.

Birefringence: Similar to biotite.

Dispersion: Weak,  $\rho > \nu$ .

$2E = 10^\circ - 60^\circ$ .

**Lepidolite** has different position of the plane of the optic axes.

Other micas, see biotite.

Other minerals than mica, see Part II.

**Phlogopite.**—A magnesium mica, near biotite, but containing little Fe.

$H = 2.5 - 3.0$ ,  $G = 2.78 - 2.85$ .

Monoclinic. (—).

Cleavage: (001), good.

Habit: Leaves, leafy aggregates.

Elongation: At right angles to (001), lath-shaped. (+).

Orientation:  $b = \mathfrak{b}$ ,  $c: a = 0^\circ$  to  $+7^\circ$ .

Colorless, yellowish, brownish, greenish.

Pleochroism: Weak with  $\mathfrak{r} > \mathfrak{b} > \mathfrak{a}$ .

$\alpha = 1.562$ ,  $\beta = 1.606$ ,  $\gamma = 1.606$ .

$\gamma - \alpha = 0.044$ ,  $\gamma - \beta = 0.0$ ,  $\beta - \alpha = 0.044$ .

Dispersion: Weak,  $\rho < \nu$ .

$2E =$  small to  $0^\circ$ .

Completely decomposed by  $H_2SO_4$ , leaving silica in thin flakes.

One of the mica group.

Other micas. Phlogopite has small to very small  $2E$ , and has symmetrical position of the plane of the optic axes.

Other minerals, see Part II.

**Ægirite.**— $NaFeSi_2O_6$ ,  $H = 6.0 - 6.5$ ,  $G = 3.5 - 3.6$ .

Monoclinic. (—).

Cleavage: (110), good.  $(110):(1\bar{1}0) = 92^\circ 49'$ .

Habit: Thin prisms, needles. Crystals bluntly terminated.





Elongation: (110):(1 $\bar{1}$ 0), lath-shaped. (-).

Orientation:  $b = \mathbf{b}$ ,  $c : \mathbf{a} = 3^\circ$  to  $6^\circ$ .

Green, yellow, brown.

Pleochroism:  $\mathbf{a}$  = deep green;  $\mathbf{b}$  = lighter green to yellowish green;

$\mathbf{c}$  = yellow to brownish.

$\alpha = 1.763$ ,  $\beta = 1.799$ ,  $\gamma = 1.813$ .

$\gamma - \alpha = 0.050$ ,  $\gamma - \beta = 0.014$ ,  $\beta - \alpha = 0.036$ .

Dispersion:  $\rho > \nu$ . Strong dispersion of bisectrices:  $c : \mathbf{a}_\rho < c : \mathbf{a}_\nu$ .

$2V = 62^\circ$ .

A pyroxene. Attacked with difficulty by acids.

Other pyroxenes. Ægirite has small extinction angle  $c : \mathbf{a}$ .

See also Part II.

Acmite occurs in sharp-pointed crystals.

Acmite.— $\text{NaFeSi}_2\text{O}_6$ ,  $H = 6.0-6.5$ ,  $G = 3.5-3.6$ .

Monoclinic. (-).

Cleavage: (110), good. (110):(1 $\bar{1}$ 0) =  $92^\circ 56'$ .

Habit: Thin prisms, laths, needles. Sharp-pointed crystals.

Elongation: (110):(1 $\bar{1}$ 0), lath-shaped. (-).

Orientation:  $b = \mathbf{b}$ ;  $c : \mathbf{a} = 3^\circ$  to  $6^\circ$ .

Brown, yellow.

Pleochroism:  $\mathbf{a}$  = brown;  $\mathbf{b}$  = light brown;  $\mathbf{c}$  = greenish yellow.

Indices: Like ægirite.

Birefringence: Like ægirite.

Dispersion: Strong inclined,  $\rho > \nu$  around  $\mathbf{a}$ .

A rare pyroxene.

Ægirite has different pleochroism.

Other pyroxenes. Like ægirite. See also Part II.

Ægirite has bluntly terminated crystals.

Grünerite.— $\text{FeSiO}_3$ ,  $H = 5.0-6.0$ ,  $G = 3.71$ .

Monoclinic. (-).

Cleavage: (110), good; (100), distinct; (010), poor. (110):(1 $\bar{1}$ 0) =  $55^\circ 49'$ .

Habit: Rods, leaves, grains.

Elongation: (110):(1 $\bar{1}$ 0), lath-shaped. (+).

Orientation:  $b = \mathbf{b}$ ,  $c : \mathbf{c} = -11^\circ$  to  $-15^\circ$ .

Colorless, brownish.

Pleochroism:  $\mathbf{c}$  = light brown;  $\mathbf{b} = \mathbf{a}$  = colorless.

$\beta = 1.73$ .

$\gamma - \alpha = 0.056$ .

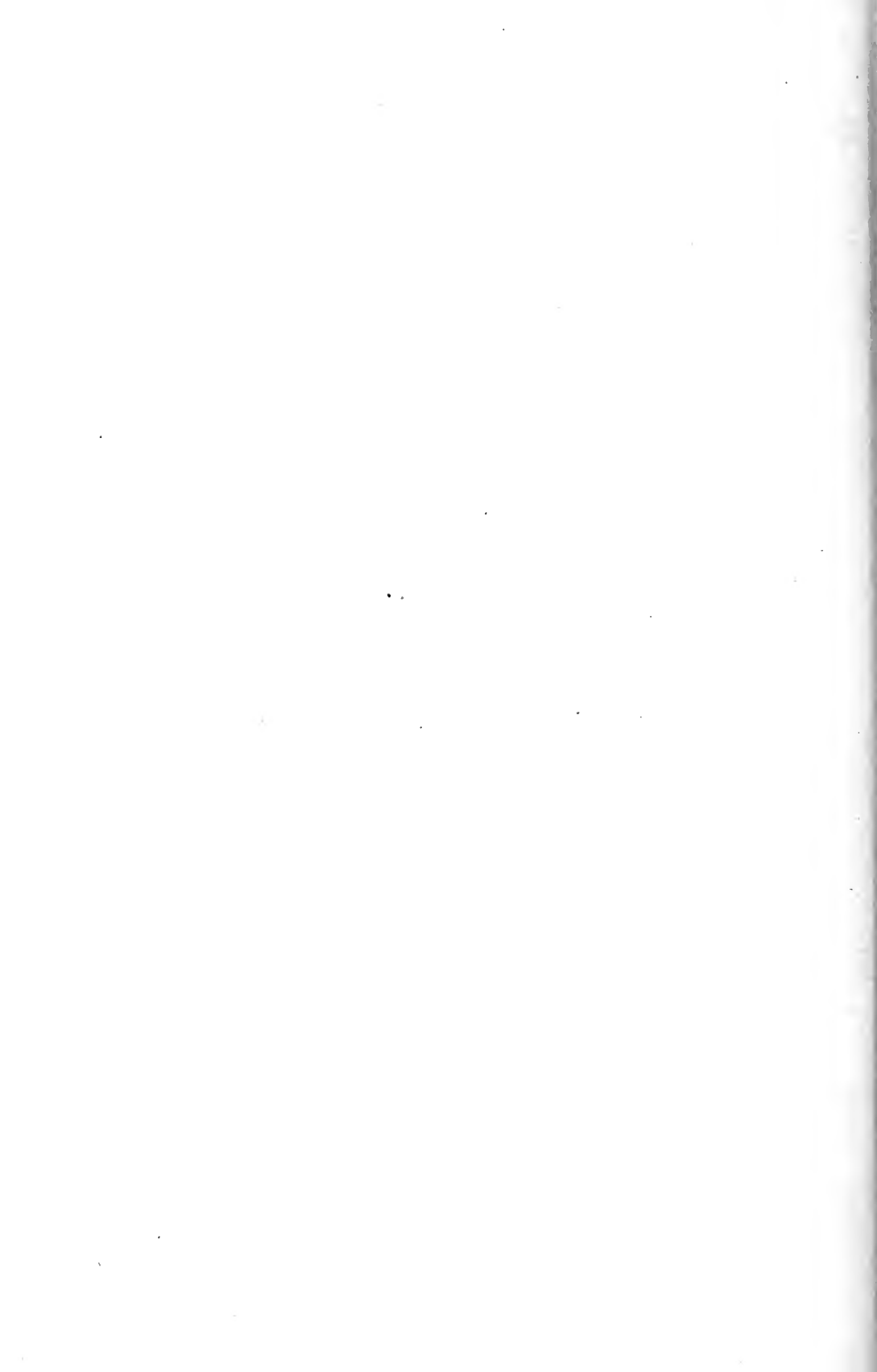
$2V = \text{large}$ .

Pyroxenes differ in cleavage and have higher extinction angles.

Basaltic hornblende.— $\text{Ca, Mg, Fe, Al}$  silicate.  $H = 5.5-6.0$ ,  $G = 3.05-3.47$ .

Monoclinic. (-).

Cleavage: (110), good; (100), distinct; (010), poor. (110):(1 $\bar{1}$ 0) =  $55.5^\circ$ .



Habit: Short prisms, grains.

Elongation: (110):(110), lath-shaped. (+)

Orientation:  $b = \mathfrak{b}$ ,  $c : \mathfrak{c} = 0^\circ$  to  $-12^\circ$ .

Brown.

Pleochroism: Strong in brown and yellow tones with  $\mathfrak{c} > \mathfrak{b} > \mathfrak{a}$ , also in green and brown tones with  $\mathfrak{a} = \text{green}$ ,  $\mathfrak{b}$  and  $\mathfrak{c} = \text{brown}$ .

$\alpha = 1.680$ ,  $\beta = 1.725$ ,  $\gamma = 1.752$ .

$\gamma - \alpha = 0.072$ ,  $\gamma - \beta = 0.027$ ,  $\beta - \alpha = 0.045$ .

$2V = 80^\circ$ .

But slightly acted upon by HCl.

An amphibole.

Other amphiboles and pyroxenes, see Part II.

Common hornblende has  $c : \mathfrak{c} = -12^\circ$  to  $-20^\circ$ , sometimes (+) character, lower double refraction, and sometimes lower  $2V$ .

Mica generally has a peculiar "bird's eye maple" appearance.

**Barkevikite.**—A variety of hornblende,  $H = 5.0\text{--}6.0$ ,  $G = 3.428$ .

Monoclinic. (—).

Cleavage: Like hornblende.

Habit: Like basaltic hornblende.

Orientation:  $b = \mathfrak{b}$ ,  $c : \mathfrak{c} = 14^\circ$ .

Brown.

Absorption:  $\mathfrak{c} > \mathfrak{b} > \mathfrak{a}$ .

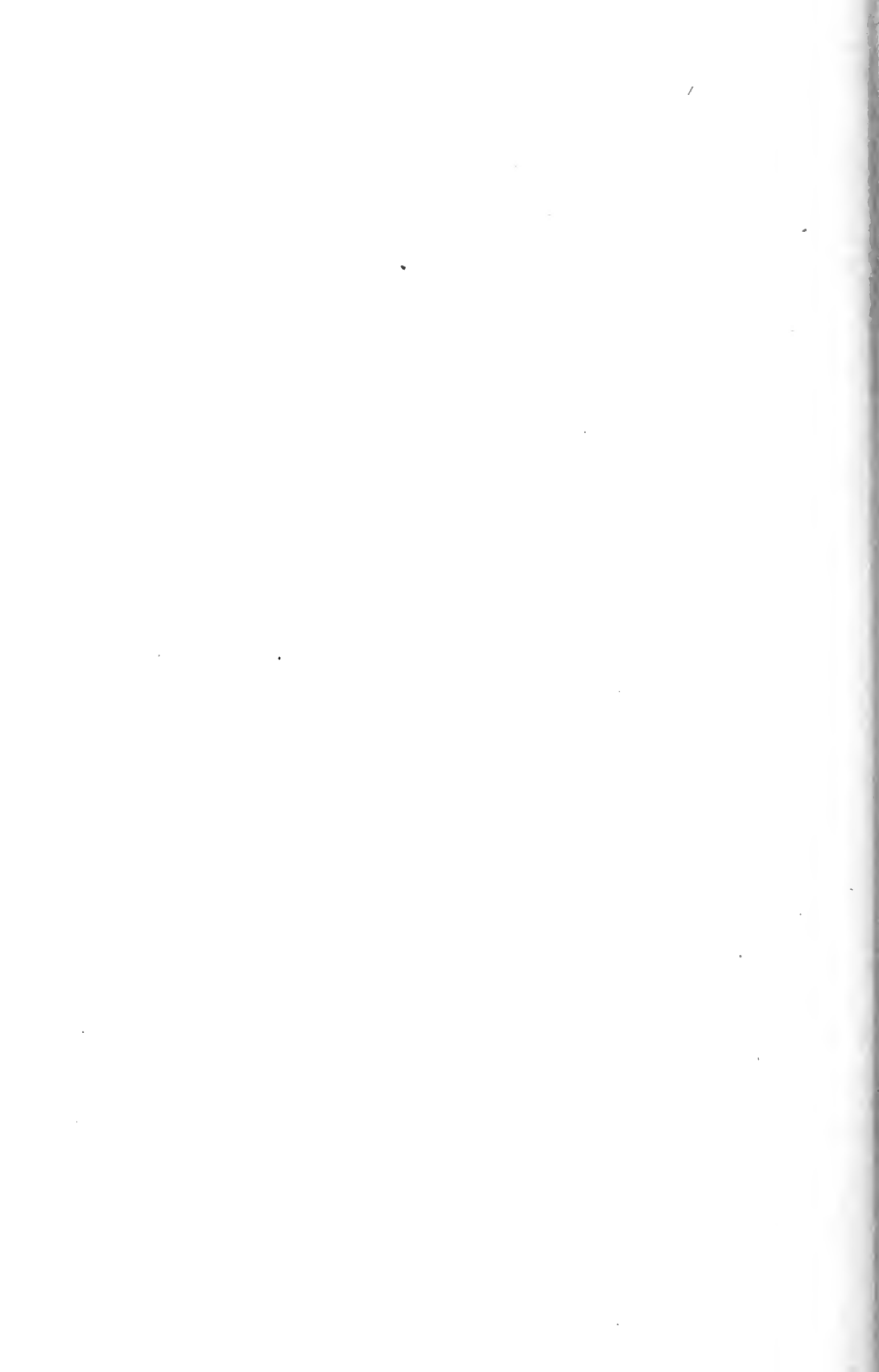
Index: Like basaltic hornblende.

Birefringence: Like basaltic hornblende.

Dispersion: Distinct  $\rho < \nu$ .

$2E = 54^\circ$  ca.

A sharp separation between barkevikite and basaltic hornblende is not possible. Use the name for the  $R_2O_3$  and  $TiO_2$  rich basaltic hornblendes with considerable alkali.



**Ottrelite.**— $H_2(Fe,Mn)_2Al_2SiO_4$ ,  $H=6.0-7.0$ ,  $G=3.53-3.55$ .

Monoclinic. (+).

Cleavage: (001), good.

Habit: Leaves plates. Tschermak twinning frequent.

Elongation: At right angles to (001), lath-shaped. (-).

Orientation:  $b=a$ ,  $c:t=0^\circ$  to  $20^\circ$ .

Blue, green, colorless.

Pleochroism:  $t$ =yellowish green, colorless;  $b$ =blue;  $a$ =olive-green.

$\beta=1.74$ .

$\gamma-\alpha=0.010$ .

Dispersion: Strong,  $\rho>\nu$ . Strong dispersion  $c:t_p>c:t_v$ .

$2E$ =large, very variable.

Hour-glass structure common.

Insoluble in HCl.

Almost exclusively confined to the phyllitic schists.

**Other minerals.** The high indices in combination with the low double refraction, the strong dispersion of the bisectrices and axes, and the peculiar pleochroism, separate the ottrelite group from all other minerals showing good (001) cleavage only.

**Clinochlore.**—Hydrous magnesium, iron, aluminium silicate.  $H=2.0-2.5$ ,  $G=2.71$ .

Monoclinic. (+).

Cleavage: (001), good.

Habit: Leaves, scales, leafy aggregates. Twinning widespread.

Elongation: At right angles to (001), lath-shaped. (-).

Orientation:  $b=b$ ,  $c:t=-2^\circ$  to  $-9^\circ$ .

Green.

Pleochroism:  $a$  and  $b$ =green;  $t$ =yellow.

$\alpha=1.585$ ,  $\beta=1.586$ ,  $\gamma=1.596$ .

$\gamma-\alpha=0.011$ ,  $\gamma-\beta=0.010$ ,  $\beta-\alpha=0.001$ .

Dispersion:  $\rho<\nu$ .

$2E=32^\circ$  to  $90^\circ$ .

One of the chlorite group.

Micas have higher birefringence and stronger or no pleochroism.

Serpentine may sometimes be difficult to separate from clinochlore.

Pennine is ( $\pm$ ),  $c:t=0^\circ$ ,  $\gamma-\alpha=0.002$ .

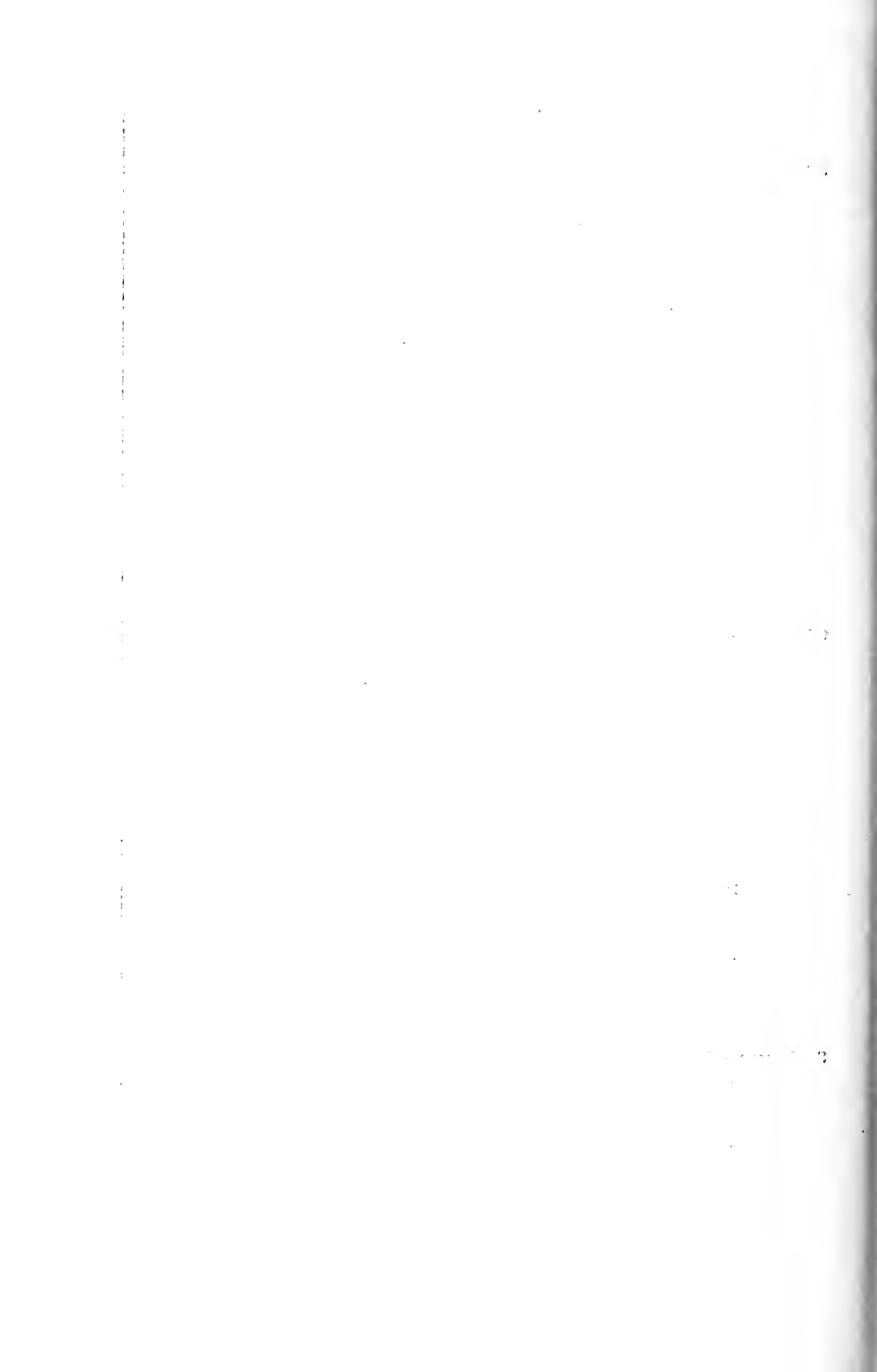
**Spodumene.**— $LiAlSi_2O_6$ ,  $H=6.5-7.0$ ,  $G=3.1-3.2$ .

Monoclinic. (+).

Cleavage: (110), (010), (100), good. (110):(1 $\bar{1}$ 0)= $93^\circ 12'$ .

Habit: Prisms, (100) tablets. (100) twinning.

Elongation: (110):(1 $\bar{1}$ 0), lath-shaped.



Orientation:  $b = \mathfrak{b}$ ,  $c : \mathfrak{c} = -23^\circ$  to  $-26^\circ$ .

Colorless, greenish.

Pleochroism: Generally non-pleochroic. Sometimes  $\mathfrak{a} = \text{amethyst}$ ,  $\mathfrak{b} = \text{amethyst}$ ,  $\mathfrak{c} = \text{colorless}$ .

$\alpha = 1.660$ ,  $\beta = 1.666$ ,  $\gamma = 1.676$ .

$\gamma - \alpha = 0.016$ ,  $\gamma - \beta = 0.010$ ,  $\beta - \alpha = 0.006$ .

Dispersion:  $\rho < \nu$ .

$2V = 54^\circ$  to  $60^\circ$ .

Unaffected by acids.

One of the pyroxenes.

Other minerals, see Part II.

Crocidolite.— $\text{Fe, Mg, Na, Ca, K amphibole}$ ,  $H = 4.0$ ,  $G = 3.20-3.30$ .

Monoclinic. (+).

Cleavage: (110), good; (100), distinct; (010), poor.  $\Delta 55.5^\circ$ .

Habit: Thread-like.

Elongation: (110):(1 $\bar{1}$ 0), narrow laths. (-).

Orientation:  $b = \mathfrak{b}$ ,  $c : \mathfrak{c} = -71^\circ$ .

Yellowish blue.

Pleochroism:  $\mathfrak{a} = \text{greenish gray}$  to colorless;  $\mathfrak{b} = \text{blue}$ ;  $\mathfrak{c} = \text{grayish violet}$ .

$\gamma - \alpha = 0.025$ .

$2E = 95^\circ$ .

Unacted upon by acids.

Other amphiboles, see Part II.

Augite.— $\text{CaMgSi}_2\text{O}_6$  with  $(\text{Mg, Fe})(\text{Al, Fe})_2\text{SiO}_6$ ,  $H = 5.0-6.0$ ,  $G = 3.2-3.6$ .

Monoclinic. (+).

Cleavage: (110), good. (110):(1 $\bar{1}$ 0) =  $93^\circ$ .

Habit: Short prisms, grains; (100) twinning.

Elongation: (110):(1 $\bar{1}$ 0), lath-shaped.

Orientation:  $b = \mathfrak{b}$ ,  $c : \mathfrak{c} = -45^\circ$  to  $-55^\circ$ .

Green, brown, reddish, violet, rarely yellow, nearly colorless.

Pleochroism: Usually weak; varies.

$\alpha = 1.698$ ,  $\beta = 1.704$ ,  $\gamma = 1.723$ .

$\gamma - \alpha = 0.025$ ,  $\gamma - \beta = 0.019$ ,  $\beta - \alpha = 0.006$ .

Dispersion: Weak,  $\rho > \nu$ .

$2V = 60^\circ$  ca.

Distinct dispersion of the bisectrices.

Unacted upon by acids.

Other pyroxenes, see Part II.

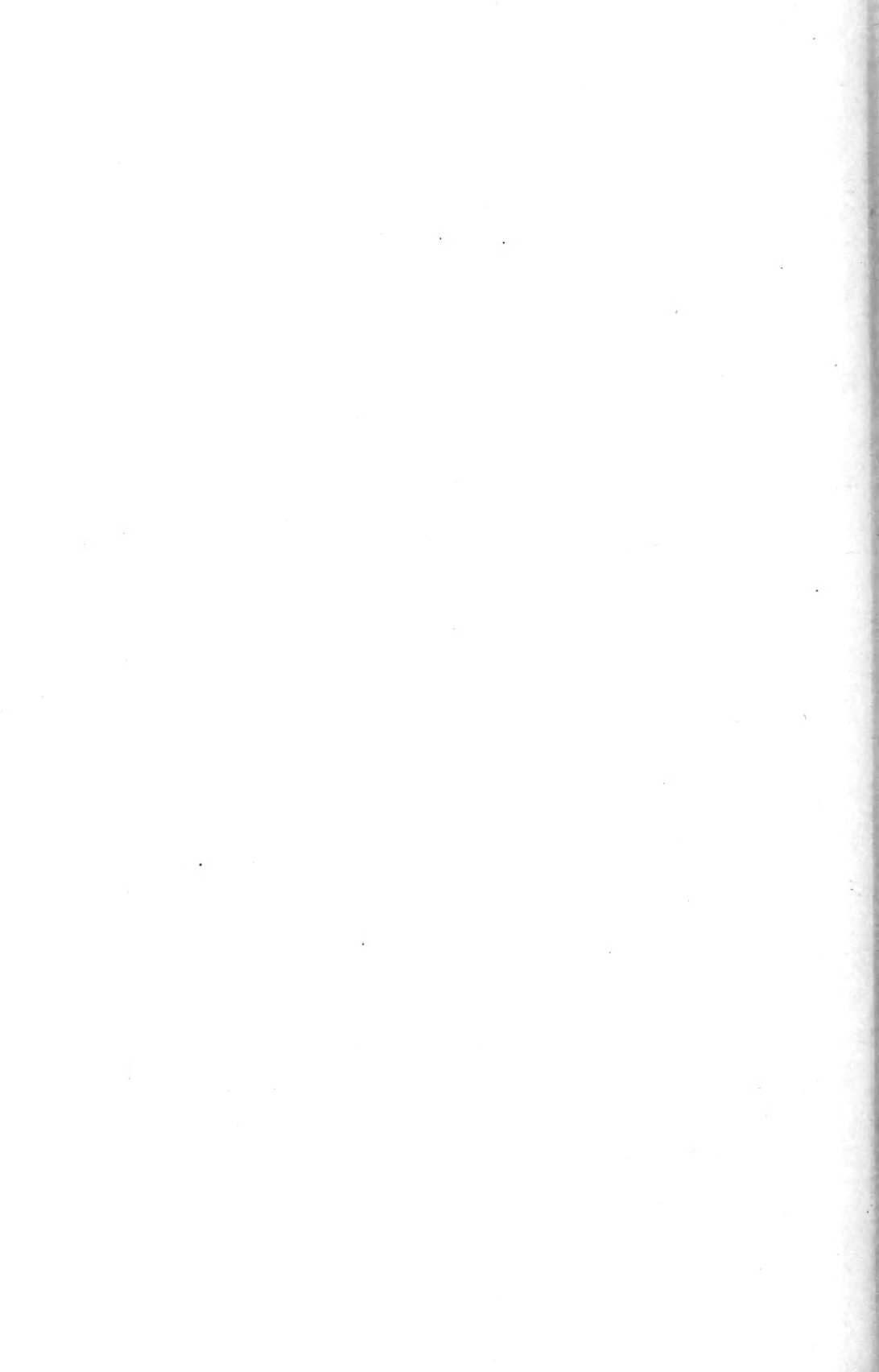
Olivine has different orientation of interference figure.

Diopside.— $\text{CaMgSi}_2\text{O}_6$ ,  $H = 5.0-6.0$ ,  $G = 3.34$ .

Monoclinic. (+).

Cleavage: (110), good. (110):(1 $\bar{1}$ 0) =  $92^\circ 50'$ .

Habit: Prismatic, grains; (100) twinning.





Elongation: (110):(110), lath-shaped.

Orientation:  $b = \mathbf{h}$ ,  $c: \mathbf{r} = -39^\circ$ .

Colorless, greenish.

Pleochroism: Weak or wanting.

$\alpha = 1.671$ ,  $\beta = 1.678$ ,  $\gamma = 1.700$ .

$\gamma - \alpha = 0.029$ ,  $\gamma - \beta = 0.022$ ,  $\beta - \alpha = 0.007$ .

Dispersion: Weak,  $\rho > \nu$ .

$2V = 59^\circ$ .

Unacted upon by acids.

All pyroxenes are characterized by right-angled cleavage on basal sections. Zonal structure is common with increasing green color outward and corresponding increase in the extinction angle.

Other pyroxenes, see Part II.

Olivine has different orientation of interference figure.

**Diallage.**—Composition near diopside, but often contains Al.  $H = 4.0$ ,  $G = 3.2-3.35$ .

Monoclinic. (+).

Cleavage: (110), (100), good. (110):(110) =  $92^\circ 50'$ .

Habit: Grains, short prisms; (100) twins frequent.

Elongation: (110):(110), lath-shaped.

Orientation:  $b = \mathbf{h}$ ,  $c: \mathbf{r} = -39^\circ$ .

Colorless, greenish, brownish.

Pleochroism: Weak,  $\mathbf{h}$  = yellowish;  $\mathbf{a} = \mathbf{r}$  = greenish.

Indices: Like diopside.

Birefringence: Like diopside.

Dispersion: Weak,  $\rho > \nu$ .

$2V = 59^\circ$  and less.

Unacted upon by acids.

The complete (100) cleavage is most characteristic. Diallage is confined in occurrence to the gabbros, peridotites, and pyroxenites.

Other pyroxenes, see Part II.

Olivine has different orientation of interference figure.

**Ægirite-augite.**—An augite rich in ægirite molecule.  $H = 6.0-6.5$ ,  $G = 3.46$ .

Monoclinic. (+) probably.

Cleavage: (110), good.  $\Delta 87^\circ$ .

Habit: Short prisms, (100) tablets.

Elongation: (110):(110), lath-shaped.

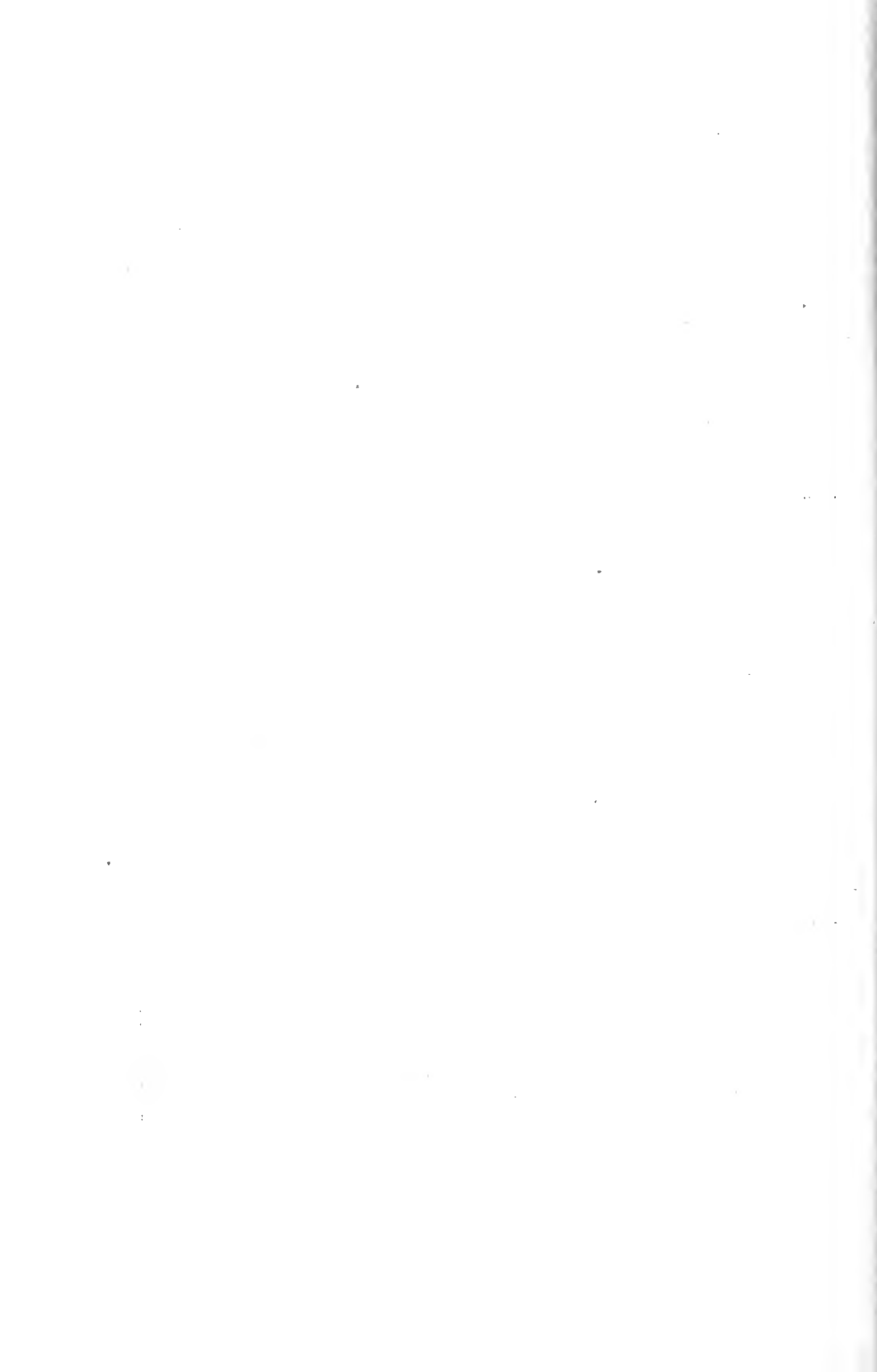
Orientation:  $b = \mathbf{h}$ ,  $c: \mathbf{r} > -55^\circ < -87^\circ$ .

Green, yellow.

Pleochroism:  $\mathbf{a}$  = grass-green;  $\mathbf{h}$  = light-green;  $\mathbf{r}$  = yellow to brownish.

$\alpha = 1.680$ ,  $\beta = 1.687$ ,  $\gamma = 1.709$ .

$\gamma - \alpha = 0.029$ ,  $\gamma - \beta = 0.022$ ,  $\beta - \alpha = 0.007$ .



Dispersion: Strong of bisectrices.

Ægirite has larger angle of extinction,  $c:r$ .

Augite has smaller extinction angle,  $c:r$ .

**Chondrodite.**— $\text{Mg}_3(\text{Mg}(\text{F},\text{OH})_2(\text{SiO}_4)_2$ ,  $H=6.0-6.5$ ,  $G=3.1-3.2$ .

Monoclinic. (+).

Cleavage: (001), distinct.

Habit: Grains, twinning lamellæ (001).

Orientation:  $b=c$ ,  $a:a=25^\circ$  to  $30^\circ$ .

Yellow, brownish, reddish.

Pleochroism:  $a=\text{yellow}$ ;  $b=c=\text{yellowish white}$ .

$\alpha=1.607$ ,  $\beta=1.619$ ,  $\gamma=1.639$ .

$\gamma-\alpha=0.032$ ,  $\gamma-\beta=0.020$ ,  $\beta-\alpha=0.012$ .

Dispersion: Weak,  $\rho \gtrsim \nu$ .

$2V=79.5^\circ$ .

Gelatinizes easily with acids.

Occurs in crystalline limestones and dolomites.

**Orthite.**—Ce epidote.  $\text{Al}(\text{SiO}_4)_3(\text{Al},\text{Fe},\text{Ce})_2(\text{CaFe})\cdot\text{CaOH}$ .  $H=5.5-6.0$ ,  
 $G=3.5-4.2$ .

Monoclinic. (Sometimes definitely +, sometimes probably -.)

Cleavage: (001), distinct.

Habit: Prisms and rods along  $b$  or  $c$ , grains.

Elongation: (001):(100), lath-shaped. ( $\pm$ ).

Orientation:  $b=b$ ,  $c:a=+36^\circ$  ca.

Brown.

Pleochroism: Distinct when anisotropic.  $r>b>a$ .

$\alpha>1.78$ ,  $\beta=1.682$ .

$\gamma-\alpha=0.032$ , to 0.0. (The birefringence sinks to zero when the mineral is altered to a gum-like substance, common in many of the Ce minerals.)

$2V$  varies.

Generally attacked by HCl.

Also called **allanite**.

Characterized by its high indices, and varying strength of double refraction, brown color, distinct pleochroism, and lack of good cleavage.

**Chondrodite** has extinction  $a:a=25^\circ$  to  $30^\circ$ .

**Pistacite** is (-) and has  $c:a=+3^\circ$ .

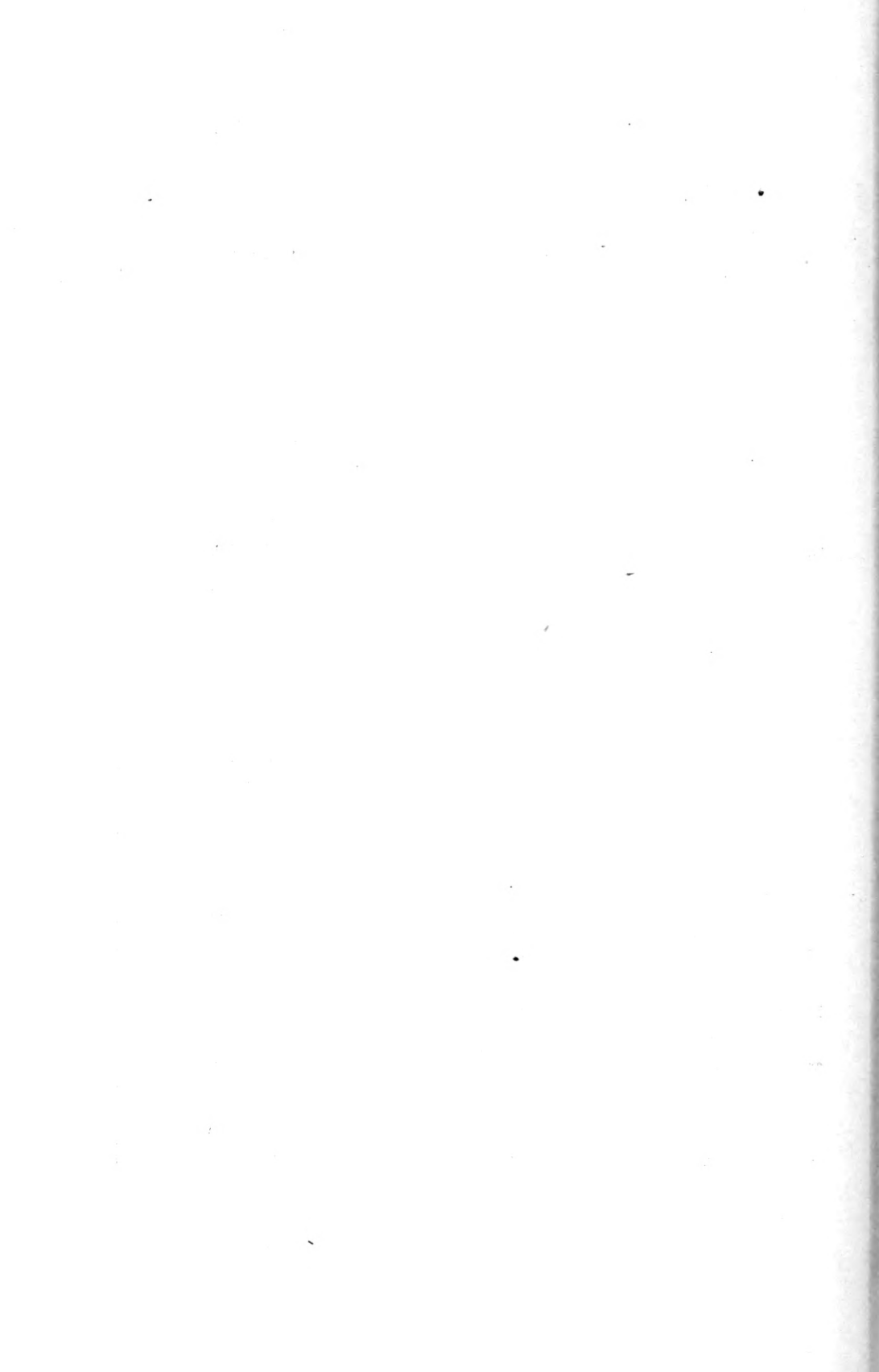
**Manganese rich piedmontite.**—See Piedmontite among negative minerals above.

**Titanolivine.**—Ti, Mg, Fe silicate.  $H=6.0$ ,  $G=3.20-3.27$ .

Monoclinic. (+).

Cleavage: Wanting.

Habit: Grains. Lamellar twinning with ( $b$ ) inclined  $20^\circ$  to the trace of the twinning plane symmetrically in each half.



Orientation:  $b = \epsilon$ .

Yellow, red.

Pleochroism:  $a = \text{red}$ ;  $b = \epsilon = \text{light-yellow}$ .

$\alpha = 1.669$ ,  $\beta = 1.678$ ,  $\gamma = 1.702$ .

$\gamma - \alpha = 0.033$ ,  $\gamma - \beta = 0.024$ ,  $\beta - \alpha = 0.009$ .

Dispersion: Strong,  $\rho \gtrsim \nu$ .

$2V = 62^\circ$  to  $63^\circ$ .

The transition between olivine and titan-olivine is gradual, though sometimes it is sharp and there are particles of one in the other.

**Astrophyllite.**— $\text{Ti, Fe, Mn, K}$  silicate.  $H = 3.0\text{--}4.0$ ,  $G = 3.3\text{--}3.4$ .

Orthorhombic. (+).

Cleavage: (100), good.

Habit: Plates, laths along  $b$ , leaves, rosettes.

Elongation: At right angles to (001), lath-shaped. ( $\pm$ ).

Orientation:  $a = a$ ,  $b = \epsilon$ .

Yellow.

Pleochroism:  $a = \text{yellow to red}$ ;  $b = \text{orange}$ ;  $\epsilon = \text{citron-yellow}$ .

$\alpha = 1.678$ ,  $\beta = 1.703$ ,  $\gamma = 1.733$ .

$\gamma - \alpha = 0.055$ ,  $\gamma - \beta = 0.030$ ,  $\beta - \alpha = 0.025$ .

Dispersion:  $\rho > \nu$ .

$2E = 160^\circ$  ca.

Insoluble in HCl.

Micas have smaller axial angle and lower indices.

Brittle micas have lower double refraction, smaller axial angle around the bisectrix emerging on cleavage flakes, and are (-).

**Titanite.**— $\text{CaSiTiO}_5$ ,  $H = 5.0\text{--}5.5$ ,  $G = 3.4\text{--}3.56$ .

Monoclinic. (+).

Cleavage: (110), distinct.  $(110):(1\bar{1}0) = 46^\circ 8'$ .

Habit: Prisms, rhombs, grains, rods.

Orientation:  $b = b$ ,  $c: \epsilon = +39^\circ$ .

Colorless, yellowish, reddish, brownish.

Pleochroism: Weak,  $\epsilon > b > a$ .

$\alpha = 1.913$ ,  $\beta = 1.921$ ,  $\gamma = 2.054$ .

$\gamma - \alpha = 0.147$ ,  $\gamma - \beta = 0.133$ ,  $\beta - \alpha = 0.008$ .

Dispersion: Very strong.  $\rho > \nu$ .

$2E_{na} = 45^\circ\text{--}68^\circ$ .

Very slightly affected by HCl.

Monazite has lower birefringence, weaker dispersion, and low extinction angle.

Brookite has parallel extinction,  $2V = 0^\circ\text{--}23^\circ$ , and a great difference in the birefringence in two directions,  $\gamma - \alpha = 0.158$ , while  $\beta - \alpha = 0.003$ .

Rutile, xenotime, hussakite, and cassiterite give no reaction for Ca.



## PART IV.

## TABLE OF MEAN INDICES OF REFRACTION.

1. Hematite.....	3.08	68. Apatite.....	1.637
2. Rutile.....	2.711	69. Gedrite.....	1.634
3. Brookite.....	2.637	70. Glaucophanes.....	1.633
4. Anatase.....	2.537	71. Aragonite.....	1.633
5. Perovskite.....	2.38	72. Melilite.....	1.632
6. Chromite.....	2.097	73. Prehnite.....	1.630
7. Cassiterite.....	2.029	74. Wollastonite.....	1.628
8. Zircon.....	1.952	75. Carpholite.....	1.627
9. Titanite.....	1.938	76. Lazulite.....	1.625
10. Melanite.....	1.873	77. Pargasite (hornblende).....	1.623
11. Fayalite.....	1.854	78. Topaz.....	1.623
12. Uwarowite.....	1.838	79. Dolomite.....	1.623
13. Spessartite.....	1.811	80. Actinolite.....	1.622
14. Monazite.....	1.811	81. Chondrodite.....	1.622
15. Almandine.....	1.810	82. Euclite.....	1.620
16. Siderite.....	1.796	83. Tremolite.....	1.617
17. Egrite.....	1.792	84. Pectolite.....	1.61
18. Corundum.....	1.766	85. Euchalite.....	1.609
19. Gahnite.....	1.765	86. Melmophane.....	1.606
20. Epidote.....	1.751	87. Calcite.....	1.601
21. Lavenite.....	1.750	88. Phlogopite.....	1.591
22. Hercynite.....	1.749	89. Clinoclure.....	1.589
23. Grossular.....	1.747	90. Celsian.....	1.589
24. Pyrope.....	1.745	91. Anhydrite.....	1.587
25. Ottrelite.....	1.741	92. Muscovite.....	1.587
26. Staurolite.....	1.741	93. Alunite.....	1.585
27. Hedenbergite.....	1.740	94. Meionite.....	1.583
28. Grünerite.....	1.73	95. Anorthite.....	1.582
29. Clinzoisite.....	1.725	96. Pennine.....	1.582
30. Vesuvianite.....	1.723	97. Biotite.....	1.581
31. Disthene.....	1.723	98. Tale.....	1.572
32. Diaspore.....	1.723	99. Brucite.....	1.567
33. Basaltic hornblende.....	1.719	100. Bytownite.....	1.565
34. Spinel.....	1.718	101. Labradorite.....	1.559
35. Wöhlerite.....	1.714	102. Mizzonite.....	1.553
36. Sapphirine.....	1.709	103. Andesine.....	1.552
37. Augite.....	1.708	104. Dipyrr.....	1.551
38. Astrophyllite.....	1.705	105. Bastite.....	1.550
39. Zoisite.....	1.702	106. Quartz.....	1.550
40. Barkevikite.....	1.701	107. Oligoclase.....	1.544
41. Egrite-augite.....	1.692	108. Hydrargillite.....	1.542
42. Axinite.....	1.691	109. Cordierite.....	1.540
43. Riebeckite.....	1.687	110. Nephelite.....	1.540
44. Dumortierite.....	1.684	111. Canada balsam.....	1.54
45. Titanolivine.....	1.683	112. Kaolin.....	1.54
46. Diopside.....	1.683	113. Albite.....	1.533
47. Orthite.....	1.682	114. Anorthoclase.....	1.527
48. Cornerupine.....	1.677	115. Gypsum.....	1.524
49. Lawsonite.....	1.673	116. Microcline.....	1.523
50. Olivine.....	1.671	117. Orthoclase.....	1.522
51. Hypersthene.....	1.670	118. Laumontite.....	1.521
52. Clinohumite.....	1.670	119. Cancrinite.....	1.515
53. Bronzite.....	1.669	120. Epistilbite.....	1.51
54. Rinkite.....	1.668	121. Thomsonite.....	1.508
55. Sillimanite.....	1.667	122. Leucite.....	1.508
56. Gehlenite.....	1.661	125. Scolecite.....	1.502
57. Enstatite.....	1.660	124. Heulandite.....	1.501
58. Monticellite.....	1.660	125. Häuynite.....	1.500
59. Jadeite.....	1.654	126. Stilbite.....	1.497
60. Mosandrite.....	1.651	127. Nesselite.....	1.495
61. Tourmaline.....	1.650	128. Hydronephelite.....	1.49
62. Rosenbuschite.....	1.65	129. Analcite.....	1.487
63. Datolite.....	1.649	130. Sodolite.....	1.483
64. Magnesite.....	1.649	131. Natrolite.....	1.482
65. Black to green hornblende.....	1.646	132. Tridymite.....	1.477
66. Anthophyllite.....	1.644	133. Opal.....	1.441
67. Andalusite.....	1.638	134. Fluorite.....	1.433



## TABLE OF MAXIMUM BIREFRINGENCES.

1. Rutile. . . . .	0.287	57. Pargasite. . . . .	0.020
2. Micaceous hematite. . . . .	0.28	58. Hedenbergite. . . . .	0.019
3. Siderite. . . . .	0.238	59. Lawsonite. . . . .	0.019
4. Magnesite. . . . .	0.202	60. Glaucophane. . . . .	0.018
5. Dolomite. . . . .	0.179	61. Monticellite. . . . .	0.017
6. Calcite. . . . .	0.172	62. Spodumene. . . . .	0.016
7. Brookite. . . . .	0.158	63. Common hornblende. . . . .	0.016
8. Aragonite. . . . .	0.156	64. Mizzonite. . . . .	0.015
9. Titanite. . . . .	0.145	65. Wollastonite. . . . .	0.015
10. Cassiterite. . . . .	0.096	66. Anorthite. . . . .	0.013
11. Anatase. . . . .	0.073	67. Dipyr. . . . .	0.013
12. Basaltic hornblende. . . . .	0.072	68. Hypersthene. . . . .	0.013
13. Zircon. . . . .	0.062	69. Cornerupine. . . . .	0.013
14. Grunerite. . . . .	0.056	70. Natrolite. . . . .	0.012
15. Astrophyllite. . . . .	0.055	71. Disthene. . . . .	0.012
16. Fayalite. . . . .	0.050	72. Johnstrupite. . . . .	0.012
17. Aegirite. . . . .	0.050	73. Mosandrite. . . . .	0.012
18. Tale. . . . .	0.050	74. Hydronephelite. . . . .	0.012
19. Diaspore. . . . .	0.048	75. Laumontite. . . . .	0.012
20. Monazite. . . . .	0.045	76. Andalusite. . . . .	0.011
21. Anhydrite. . . . .	0.044	77. Clinocllore. . . . .	0.011
22. Datolite. . . . .	0.044	78. Dumortierite. . . . .	0.011
23. Phlogopite. . . . .	0.044	79. Gypsum. . . . .	0.010
24. Biotite. . . . .	0.040	80. Axinite. . . . .	0.010
25. Lavenite. . . . .	0.040	81. Staurolite. . . . .	0.010
26. Muscovite. . . . .	0.038	82. Ottrelite. . . . .	0.010
27. Pectolite. . . . .	0.038	83. Epistilbite. . . . .	0.010
28. Lazulite. . . . .	0.036	84. Albite. . . . .	0.010
29. Olivine. . . . .	0.035	85. Corundum. . . . .	0.009
30. Humite. . . . .	0.035	86. Quartz. . . . .	0.009
31. Meionite. . . . .	0.035	87. Enstatite. . . . .	0.009
32. Prehnite. . . . .	0.033	88. Bronzite. . . . .	0.009
33. Titanolivine. . . . .	0.033	89. Cordierite. . . . .	0.009
34. Pistacite. . . . .	0.032	90. Topaz. . . . .	0.009
35. Chondrodite. . . . .	0.032	91. Zoisite. . . . .	0.009
36. Orthite. . . . .	0.032	92. Kaolin. . . . .	0.008
37. Diopside. . . . .	0.029	93. Clinzoisite. . . . .	0.008
38. Jadeite. . . . .	0.029	94. Scolecite. . . . .	0.007
39. Aegirite-augite. . . . .	0.029	95. Heulandite. . . . .	0.007
40. Canerinite. . . . .	0.028	96. Orthoclase. . . . .	0.006
41. Thomsonite. . . . .	0.028	97. Gehlenite. . . . .	0.006
42. Actinolite. . . . .	0.027	98. Enigmatite. . . . .	0.006
43. Tremolite. . . . .	0.026	99. Stilbite. . . . .	0.006
44. Wöhlerite. . . . .	0.026	100. Sapphirine. . . . .	0.005
45. Rosenbuschite. . . . .	0.026	101. Melilite. . . . .	0.005
46. Tourmaline. . . . .	0.025	102. Nephelite. . . . .	0.005
47. Augite. . . . .	0.025	103. Riebeckite. . . . .	0.004
48. Anthophyllite. . . . .	0.024	104. Apatite. . . . .	0.004
49. Hydrargillite. . . . .	0.023	105. Eucoelite. . . . .	0.003
50. Carpholite. . . . .	0.022	106. Phillipsite. . . . .	0.003
51. Sillimanite. . . . .	0.022	107. Euclialite. . . . .	0.002
52. Brucite. . . . .	0.021	108. Tridymite. . . . .	0.002
53. Gedrite. . . . .	0.021	109. Vesuvianite. . . . .	0.002
54. Barkevikite. . . . .	0.021	110. Pennine. . . . .	0.002
55. Alunite. . . . .	0.020	111. Leucite. . . . .	0.001
56. Melinophane. . . . .	0.020		

## NEWTON'S COLOR SCALE.

(Modified from Quincke.)

No.	Difference in Wave Length.	Phase Difference for Na Light.	Interference Colors Between Crossed Nicols.	Interference Colors Between Parallel Nicols.
1	0.000000 mm.	0	Black. ....	Bright white
2	0.000040	.....	Iron gray. ....	White
3	0.000097	.....	Lavender gray. ....	Yellowish white
4	0.000158	$\frac{1}{4}$	Grayish blue. ....	Brownish white
5	0.000218	.....	Clearer gray. ....	Brownish yellow
6	0.000234	.....	Greenish white. ....	Brown
7	0.000259	.....	Almost pure white. ....	Light red
8	0.000267	.....	Yellowish white. ....	Carmine
9	0.000275	.....	Pale straw-yellow. ....	Dark reddish brown
10	0.000281	.....	Straw yellow. ....	Deep violet
11	0.000306	$\frac{1}{2}$	Light yellow. ....	Indigo
12	0.000332	.....	Bright yellow. ....	Blue
13	0.000430	.....	Brownish yellow. ....	Grayish blue
14	0.000505	$\frac{3}{4}$	Reddish orange. ....	Bluish green
15	0.000536	.....	Red. ....	Pale green
16	0.000551	.....	Deep red. ....	Yellowish green
17	0.000565	.....	Purple. ....	Lighter green
18	0.000575	.....	<b>Violet.</b> ....	Greenish yellow
19	0.000589	1	Indigo. ....	Golden yellow
20	0.000664	.....	Sky blue. ....	Orange
21	0.000728	.....	Greenish blue. ....	Brownish orange
22	0.000747	.....	Green. ....	Light carmine
23	0.000826	.....	Lighter green. ....	Purplish red
24	0.000843	.....	Yellowish green. ....	Violet purple
25	0.000866	.....	Greenish yellow. ....	Violet
26	0.000910	$\frac{1}{2}$	Pure yellow. ....	Indigo.
27	0.000948	.....	Orange. ....	Dark blue
28	0.000998	.....	Bright orange red. ....	Greenish blue
29	0.001101	.....	Dark violet red. ....	Green
30	0.001128	.....	Light bluish violet. ....	Yellowish green
31	0.001151	2	Indigo. ....	Impure yellow
32	0.001258	.....	Greenish blue. ....	Flesh colored
33	0.001334	.....	Sea-green. ....	Brownish red
34	0.001376	.....	Brilliant green. ....	Violet
35	0.001426	$\frac{3}{4}$	Greenish yellow. ....	Violet
36	0.001495	.....	Flesh color. ....	Sea-green
37	0.001534	.....	Carmine. ....	Green
38	0.001621	.....	Dull purple. ....	Dull sea-green
39	0.001652	.....	Violet gray. ....	Yellowish green
40	0.001682	.....	Grayish blue. ....	Greenish yellow
41	0.001711	.....	Dull sea-green. ....	Yellowish gray
42	0.001744	3	Bluish green. ....	Lilac
43	0.001811	.....	Light green. ....	Carmine
44	0.001927	.....	Light greenish gray. ....	Grayish red
45	0.002007	.....	Whitish gray. ....	Bluish gray
46	0.002048	.....	Flesh red. ....	Green

## TABLE OF SPECIFIC GRAVITIES.

Cassiterite.....	6.65	Crossite.....	3.15
Hematite.....	5.20	Spodumen.....	3.15
Magnetite.....	5.10	Tourmaline.....	3.12
Monazite.....	5.10	Hornblende.....	3.12
Pyrite.....	5.05	Magnesite.....	3.10
Pseudobrookite.....	4.98	Glaucophane.....	3.10
Ilmenite.....	4.65	Lawsonite.....	3.09
Zircon.....	4.53	Lazulite.....	3.06
Xenotime.....	4.52	Eucolite.....	3.05
Chromite.....	4.45	Actinolite.....	3.02
Rutile.....	4.25	Melinophane.....	3.01
Fayalite.....	4.14	Biotite.....	3.00
Picotite.....	4.08	Gehlenite.....	3.00
Perovskite.....	4.03	Tremolite.....	3.00
Melanite.....	3.95	Melilite.....	3.00
Corundum.....	3.95	Mosandrite.....	2.98
Siderite.....	3.94	Datolite.....	2.95
Brookite.....	3.94	Anhydrite.....	2.95
Anatase.....	3.88	Aragonite.....	2.94
Orthite.....	3.85	Carpholite.....	2.94
Pleonaste.....	3.82	Eudialyte.....	2.92
Ænigmatite.....	3.81	Dolomite.....	2.90
Pyrope.....	3.75	Delesite.....	2.89
Staurolite.....	3.72	Wollastonite.....	2.88
Grünerite.....	3.71	Prehnite.....	2.87
Periclas.....	3.65	Muscovite.....	2.85
Disthene.....	3.62	Lepidolite.....	2.85
Spinel.....	3.60	Paragonite.....	2.84
Grossular.....	3.56	Phlogopite.....	2.81
Topaz.....	3.55	Pectolite.....	2.81
Hedenbergite.....	3.54	Anorthite.....	2.76
Lavenite.....	3.53	Talc.....	2.75
Ægirite.....	3.53	Meionite.....	2.73
Uwarowite.....	3.51	Bytownite.....	2.73
Sapphirine.....	3.49	Pennine.....	2.73
Rinkite.....	3.48	Calcite.....	2.71
Titanite.....	3.48	Clinocllore.....	2.71
Ægirite-augite.....	3.46	Bastite.....	2.70
Arfvedsonite.....	3.45	Labradorite.....	2.70
Hypersthene.....	3.45	Alunite.....	2.70
Wöhlerite.....	3.43	Andesine.....	2.67
Barkevikite.....	3.43	Quartz.....	2.65
Titan-augite.....	3.41	Cordierite.....	2.63
Vesuvianite.....	3.41	Albite.....	2.62
Diaspore.....	3.40	Kaolin.....	2.62
Piedmontite.....	3.40	Mizzonite.....	2.61
Pistacite (Epidote).....	3.39	Anorthoclase.....	2.59
Augite.....	3.36	Nephelite.....	2.58
Olivine.....	3.36	Dipyr.....	2.57
Astrophyllite.....	3.35	Serpentine.....	2.57
Prismatine.....	3.34	Orthoclase.....	2.55
Jadeite.....	3.34	Microcline.....	2.55
Zoisite.....	3.31	Leucite.....	2.47
Rosenbuschite.....	3.31	Brucite.....	2.39
Diopside.....	3.30	Haüyite.....	2.38
Bronzite.....	3.29	Sodalite.....	2.38
Dumortierite.....	3.29	Hydrargillite.....	2.38
Axinite.....	3.28	Thomsonite.....	2.35
Diallage.....	3.27	Gypsum.....	2.32
Corneupine.....	3.27	Tridymite.....	2.30
Forsterite.....	3.26	Laumontite.....	2.30
Sillimanite.....	3.24	Glaucosite.....	2.30
Johnstrupite.....	3.20	Scolecite.....	2.28
Monticellite.....	3.20	Hydronephelite.....	2.26
Fluorite.....	3.19	Epistilbite.....	2.25
Thuringite.....	3.17	Natrolite.....	2.21
Apatite.....	3.16	Opal.....	2.21
Andalusite.....	3.15	Heulandite.....	2.20
Anthophyllite.....	3.15	Phillipsite.....	2.20
Humite.....	3.15	Hyalite.....	2.17
Chondrodite.....	3.15	Analcite.....	2.16
Clinohumite.....	3.15	Stilbite.....	2.16
Enstatite.....	3.15	Hydromagnesite.....	2.16

### Separation by Heavy Solutions.

The rock, whose minerals are to be separated, is reduced to small size by crushing, not grinding, in a mortar, sifted through a sieve with meshes of 0.5 mm., and washed to free it from dust.

**Thoulet's\*** solution is a solution of potassium mercuric iodide, having a maximum density of 3.196. It is made by dissolving mercuric iodide and potassium iodide in cold water in the proportion  $\text{KI}:\text{HgI}_2=1:1.24$ , and evaporated on a water-bath until a crystalline coat forms on the surface, or until a crystal of fluorite floats upon it. Upon cooling, the contraction raises the density to 3.196. It is afterwards filtered, and should be perfectly transparent and of a yellowish-green color.

This solution can be diluted with water without decomposition, and may be reduced to a specific gravity of 1.0 and again increased by evaporation on the water-bath. An excess of  $\text{HgI}_2$  causes a yellow hydrous double salt to separate in acicular crystals. KI in excess separates in the form of cubes and does no harm to the solution.

Thoulet's solution is decomposed by metallic iron, and all such should be previously removed by the magnet. It is extremely poisonous, and great care should be taken in using it.

**Klein's†** solution is made of cadmium borotungstate ( $2\text{H}_2\text{O}\cdot 2\text{CdO}\cdot \text{B}_2\text{O}_3\cdot 9\text{WO}_3+16\text{ aq.}$ ) dissolved in ten times its weight of water. It is a light-yellow, innoxious solution, with a specific gravity of 3.28 at  $15^\circ\text{C.}$ , and is miscible with water without decomposition. It is decomposed by metallic iron, zinc, and lead, and by carbonates.

**Braun's‡** solution. Methylene iodide ( $\text{CH}_2\text{I}_2$ ), a strongly refracting yellow fluid. It is miscible with benzene and does not attack metallic substances. It has a specific gravity of

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\* Neues Jahrbuch, B. Band I., 1881, p. 179.

† Comp. Rend., 1881, 93, p. 318; Bull. Soc. Min. Fr., 1881, 4, p. 149.

‡ Neues Jahrbuch II., 1886, p. 72.

3.3375 at 10° C., 3.3243 at 16° C., and 3.3155 at 20° C. Its index of refraction at 16° is 1.74092.

To determine the exact specific gravity of the diluted solution, a direct test may be made or a series of indicators may be used. The following were used by V. Goldschmidt:\*

1. Sulphur . . . . .	Girgenti	G=2.070
2. Hyalite . . . . .	Waltseh	2.160
3. Opal . . . . .	Scheiba	2.212
4. Natrolite. . . . .	Brevig	2.246
5. Pitchstone. . . . .	Meissen	2.284
6. Obsidian. . . . .	Lipari	2.362
7. Pearlite. . . . .	Hungary	2.397
8. Leucite . . . . .	Vesuvius	2.465
9. Adularia. . . . .	St. Gotthard	2.570
10. Elæolite. . . . .	Brevig	2.617
11. Quartz . . . . .	Middleville	2.650
12. Labradorite. . . . .	Labrador	2.689
13. Calcite. . . . .	Rabenstein	2.715
14. Dolomite . . . . .	Muhrwinkel	2.733
15. Dolomite. . . . .	Rauris	2.868
16. Prehnite . . . . .	Kilpatrick	2.916
17. Aragonite . . . . .	Bilin	2.933
18. Actinolite . . . . .	Zillerthal	3.020
19. Andalusite . . . . .	Bodenmais	3.125
20. Apatite. . . . .	Ehrenfriedersdorf	3.180

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\* Neues Jahrbuch, B. Band I, 1881, p. 215; Verhandlung K. K. Reichsanstalt, 1883, p. 68.

### Vibration Directions in Accessories.

**Determination of the plane of vibration of the lower nicol.** The absorption of biotite is greatest, consequently it is darkest, when its cleavage direction is parallel to the plane of vibration of the polarizer.

Tourmaline extinguishes vibrations at right angles to the optic axis, that is, it absorbs the ordinary ray, and only the light rays vibrating parallel to crystallographic *c* emerge. It is therefore dark when the elongation (*c*) is at right angles to the vibration-plane of the polarizer.

**Determination of the direction of  $\epsilon$  in the one-quarter undulation mica-plate.** Examine the interference figure produced by the mica-plate, using it as a mineral section. The axis of least ease of vibration  $\epsilon$  is the line joining the loci of the hyperbolæ.  $\alpha$  is at right angles to this line.

**Determination of the  $\epsilon$  direction in the gypsum-plate (Red of the First Order).** Examine the interference figure, using the gypsum-plate as a mineral section. The line joining the quadrants showing the lowest color (yellow) is the  $\epsilon$  direction. The explanation is given on page 26.

**Determination of the  $\epsilon$  direction in a quartz or mica-wedge.** See "Determination of the Relative Values of Two Vibration Directions" (p. 22). Use the wedge as a mineral section and use a mica-plate, in which the  $\epsilon$  direction has been determined, as an accessory.

## MINERALS ARRANGED ACCORDING TO CRYSTALLINE SYSTEMS.

ISOMETRIC.	HEXAGONAL.	MONOCLINIC.	MONOCLINIC.
Almandine.	Alunite.	Acmite.	Orthite.
Analcite.	Apatite.	Actinolite.	Orthoclase.
Beckelite.	Brucite.	Ægirite.	Ottrelite.
Chromite.	Calcite.	Ægirite-augite.	Paragonite.
Fluorite.	Canerinite.	Ægirite - hedenber-	Pargasite.
Gahnite.	Chabazite.	gite.	Pectolite.
Garnets.	Corundum.	Anomite.	Pennine.
Grossular.	Dolomite.	Arfvedsonite.	Phillipsite.
Häüynite.	Eucolite.	Augite.	Phlogopite.
Hercynite.	Eudialyte.	Baddeleyite.	Piedmontite.
Hessonite.	Gmelinite.	Barkevikite.	Pistacite.
Lazulite.	Graphite.	Biotite.	Riebeckite.
Leucite.	Hematite.	Carpholite.	Rinkite.
Magnetite.	Hydronephelite?	Celsian.	Rosenbuschite.
Melanite.	Ilmenite.	Chondrodite.	Salite.
Noselite.	Magnesite.	Clinocllore.	Sanidine.
Periclase.	Nephelite.	Clinohumite.	Sapphirine.
Perofskite.	Pyrrhotite.	Clinozoisite.	Scolecite.
Picotite.	Quartz.	Crocidolite.	Spodumene.
Pleonaste.	Siderite.	Crossite.	Stilbite.
Pyrite.	Tourmaline.	Cunningtonite.	Thuringite.
Sodalite.	Tridymite.	Datolite.	Titanaugite.
Spessartite.		Delessite.	Titanite.
Spinel.	ORTHORHOMBIC.	Diallage.	Titanolivine.
Pyrope.	Andalusite.	Diopside.	Tremolite.
Uwarowite.	Anhydrite.	Epistilbite.	Uralite.
	Anthophyllite.	Gastalkite.	Uranite.
	Aragonite.	Glaucophane.	Wöhlerite.
	Astrophyllite.	Grünerite.	Wollastonite.
Anatase.	Bronzite.	Gypsum.	Zinnwaldite.
Apophyllite.	Brookite.	Harmotome.	
Cassiterite.	Cordierite.	Hastingsite.	TRICLINIC.
Dipyrr.	Cornerupine.	Hedenbergite.	Ænigmatite.
Hussakite.	Diaspore.	Heulandite.	Albite.
Melilite.	Dumortierite.	Hornblende, Com-	Andesine.
Meliphanite.	Enstatite.	mon.	Andesine-labrado-
Rutile.	Fayalite.	Hornblende, Basal-	rite.
Scapolite.	Forsterite.	tic.	Anorthite.
Vesuvianite.	Goethite.	Hyalophane.	Axinite.
Xenotime.	Humite.	Hydrargillite.	Bytownite.
Zircon.	Hypersthene.	Jadeite.	Bytownite-
	Lawsonite.	Johnstrupite.	anorthite.
	Monticellite.	Kaolin.	Cyanite.
	Natrolite.	Kataphorite.	Hainite.
	Olivine.	Laumprophyllite.	Labradorite.
	Prehnite.	Laumontite.	Labradorite-
	Pseudobrookite.	Lavenite.	bytownite.
	Serpentine?	Lazulite.	Microcline.
	Sillimanite.	Lepidolite.	Oligoclase.
	Staurolite.	Manganpectolite.	Oligoclase-albite.
	Talc.	Monazite.	Oligoclase-ande-
	Thomsonite.	Mosandrite.	sine.
	Thulite.	Muscovite.	
	Topaz.	Nontronite.	
	Zoisite.	Omphacite.	

## MINERALS WHICH OCCUR IN NEEDLE-LIKE CRYSTALS.

Actinolite.	Cancrinite.	Hydronephelite.	Tremolite.
Ægirite.	Datolite.	Natrolite.	Topaz.
Apatite.	Dumortierite.	Sillimanite.	Tourmaline.
Aragonite.	Hydromagnesite.	Stilbite.	Wollastonite.

## MINERALS WHICH OCCUR IN FIBROUS AGGREGATES.

Chalcedony.	Hydrargillite.	Sericite.
Datolite.	Kaolin.	Serpentine.
Gypsum.	Natrolite.	Sillimanite.
	Prehnite.	Talc.

## MINERALS WHICH OCCUR IN RADIATING GROUPS OF FIBRES

Chlorite.	Natrolite.	Thomsonite.
Chalcedony.	Pectolite.	Other zeolites.
Delessite.	Stilbite.	

## MINERALS WHICH OCCUR AS CAVITY FILLINGS.

Carbonates.	Chalcedony.	Zeolites.
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## ALTERATION PRODUCTS WHICH OCCUR IN MINUTE SHREDS.

Kaolin.	Talc.	White mica. (Paragonite, sericite.)
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## ALPHABETICAL LIST OF THE ROCK-FORMING MINERALS.

Name.	System.	Mean Index.	Maxim. Birefrim.	Optical Char.	Elong. Char.	2V or 2E.	Orientation.
Actinolite. . . . .	Mono. . . . .	1.622	0.027	—	+	2V = 80°	c:t = -15°
Ægrite. . . . .	Mono. . . . .	1.792	0.050	—	—	2V = 62°	c:a = 3° to 6°
Ægrite-augite. . . . .	Mono. . . . .	1.692	0.029	+	—	.....	c:t > -55° < -87°.
Enigmatite. . . . .	Triel. . . . .	High	0.006	+	±	2E = 60° ca.	On (100), 3° to 5°.
Albite. . . . .	Triel. . . . .	1.533	0.010	+	.....	2V = 77°-84°	*
Allanite. See Orthite.							
Almandine. . . . .	Isom. . . . .	1.810					
Alumite. . . . .	Hex. . . . .	1.585	0.020		+		c:a = 3° to 6°
Analcite. . . . .	Isom. . . . .	1.487					c:t > -55° < -87°.
Anatase. . . . .	Tetr. . . . .	2.537	0.073		—		On (100), 3° to 5°.
Andalusite. . . . .	Ortho. . . . .	1.638	0.011	—		2V = 85°	*
Andesine. . . . .	Triel. . . . .	1.553	0.006	+	.....	2V = 80°-90	c = a, a = t.
Anhydrite. . . . .	Ortho. . . . .	1.587	0.044	+	+	2V = 43°, 2E = 71.5°	c = a, a = t.
Anomite. . . . .	Mono. . . . .	1.581	0.040	—	—	2E = 102°-68°	c:t = 0° to 4°.
Anorthite. . . . .	Triel. . . . .	1.582	0.013	—	.....	2V = 77°-80°	*
Anorthoclase. . . . .	Triel. . . . .	1.527	0.006	—	.....	2V = 43°-53°	*
Anthophyllite. . . . .	Ortho. . . . .	1.644	0.024	±	+	2V = ±90°	c = t, a = a.
Antigorite. . . . .	Ortho. . . . .	1.567	0.011	±	+	2E = 16°-98°	a = a, b = t.
Apatite. . . . .	Hex. . . . .	1.637	0.004	—	—		c = a, b = t.
Aragonite. . . . .	Ortho. . . . .	1.633	0.156	—	—	2V = 18°, 2E = 30°	c:a = -70° to -80°.
Arfvedsonite. . . . .	Mono. . . . .	High	Low	±	—	2V = Large	a = a, b = t.
Astrophyllite. . . . .	Ortho. . . . .	1.705	0.055	+	±	2E = 160° ca.	c:t = -45° to -55°.
Augite. . . . .	Mono. . . . .	1.708	0.025	+	.....	2V = 60°-68°	
Automolite. See Galmite.							
Axinite. . . . .	Triel. . . . .	1.691	0.010	—	.....	2E = Large	c:a = -11°.
Baddeleyite. . . . .	Mono. . . . .	High	High	—	±	2E = 70°-75°	c:t = 14°.
Barkevikite. . . . .	Mono. . . . .	1.701	Low	.....	.....	2E = 54°	c = t, a = a.
Basite. . . . .	Ortho. . . . .	1.550	Low	—	+	2E = 20°-90°	

\* See p. 78.

## ALPHABETICAL LIST OF THE ROCK-FORMING MINERALS—Continued.

Name.	System.	Mean Index.	Maxim. Birefrim.	Optical Char.	Elong. Char.	2V or 2E.	Orientation.
Biotite.	Mono. . .	1.581	0.040	—	+	2E=0°-72°	c: a = -0° to -7°.
Bronzite.	Ortho. . .	1.669	0.009	+	+	2E=106°	c = t, b = a.
Brookite.	Ortho. . .	2.637	0.158	+	+	2V=0°-23°	a = t, b or c = a.
Bruceite.	Hex. . .	1.567	0.021	+	—		*
Bytownite.	Triclin. . .	1.565	0.008	—	.....	2V=80°-90°	
Calcite.	Hex. . .	1.601	0.172	—	—		
Cancrinite.	Hex. . .	1.515	0.028	—	—	2V=60°	c: t = 4° ca.
Carpholite.	Mono. . .	1.627	0.022	+	+		c: a = -62°.
Cassiterite.	Tetr. . .	2.029	0.096	+	—	2V=86°	c = a.
Celsian.	Mono. . .	1.589	0.010	+	—	2E=10°-40°	
Chalcodony.	Ortho. . .	1.538	0.011	+	.....		a: t = 23° to 30°.
Chiasolite.							
Chlorite.	Mono. . .	1.622	0.032	+	—	2V=80°	
Chondrodite.	Ison. . .	2.097			.....		
Chromite.							
Chrysolite.	See Olivine.						
Clinocllore.		1.589	0.011	+	—	2E=32°-90°	c: t = -2° to -9°.
Clinohumite.	Mono. . .	1.670		+	.....	2V=76.5°	c: a = 7° to 15°.
Clinzoisite.	Mono. . .	1.725	0.008	+	±	2V=80°-90°	c: a = -3°.
Cordierite.	Ortho. . .	1.540	0.009	—	—	2E=63°-150°	c = a, b = t.
Correnurpine.	Ortho. . .	1.677	0.013	—	.....	2E=14°-32°	c = a, b = t.
Corundum.	Hex. . .	1.766	0.009	—	+	2E=90°	c: t = -71°.
Crocidolite.	Mono. . .	0.025	0.008	+	—	2E=Large	c: b = -20° to -30°.
Crossite.	Mono. . .			—	.....		
Cyanite.	See Disthene.						
Datolite.		1.649	0.044	—	.....	2V=74°	c: a = 1° to 4°.
Desmine.	See Stilbite.						
Diallage.	Mono. . .	1.683	0.029	+	.....	2V=50°	c: t = -39°.

\* See p. 78.

## ALPHABETICAL LIST OF THE ROCK-FORMING MINERALS—Continued.

Name.	Systcm.	Mean Index.	Maxim. Birefrin.	Optical Char.	Elong. Char.	2V or 2E.	Orientation.
Diaspore. . . . .	Ortho. . . .	1.723	0.048	+	—	2V=85°	c=a, a=c.
Dichroite. See Cordierite. . . . .							
Diopside. . . . .	Mono. . . .	1.683	0.029	+	—	2V=59°	c:t=—39°.
Disthene. . . . .	Tricl. . . .	1.723	0.012	—	+	2V=82°	a nearly 1 to (100.)
Dolomite. . . . .	Hex. . . .	1.623	0.179	—	—		
Dumortierite. . . . .	Ortho. . . .	1.684	0.011	—	—	2V=30°, 2E=54°	c=a, a=c.
Enstatite. . . . .	Ortho. . . .	1.660	0.009	+	+	2V=70°	c=t, b=a.
Epidote. See Pistachite. . . . .							
Epistilbite. . . . .	Mono. . . .	1.51	0.010	—	+	2E=67°-83°	c:t=—9°.
Eucolite. . . . .	Hex. . . .	1.620	0.003	—	+	2E=Anom. 50°	
Euxalyte. . . . .	Hex. . . .	1.609	0.002	+	—	2E=Anom. 50°	
Fayalite. . . . .	Ortho. . . .	1.854	0.050	—	—	2V=50°	a=t, b=a.
Fibrolite. See Sillimanite. . . . .							
Fluorite. . . . .	Isom. . . .	1.433					
Forsterite. . . . .	Ortho. . . .	1.659	High	+	—	2V=86°	a=t, b=a.
Gahnite. . . . .	Isom. . . .	1.765					
Gastaldite. . . . .	Mono. . . .	1.648	0.016	—	+	2E=70°	c:t=—6°.
Gedrite. . . . .	Ortho. . . .	1.634	0.021	—	+	2V=57°-79°	c=t, a=a.
Gehlenite. . . . .	Tetr. . . .	1.661	0.006	—	—		
Gibbsite. See Hydrargillite. . . . .							
Glauconite. . . . .	? . . . .	1.633	Low	—	—	2E=0°-40°	
Glaucophan. . . . .	Mono. . . .	1.633	0.018	—	+	2V=50°, 2E=85.5°	c:t=—1° to —6°.
Grossular. . . . .	Isom. . . .	1.750					
Grünertite. . . . .	Mono. . . .	1.73	0.056	—	+	Large	c:t=—11° to —15°.
Gypsum. . . . .	Mono. . . .	1.524	0.010	+	—	2V=58°-61°, 2E=104°	c:t=—53°.
Harmotome. . . . .	Mono. . . .	1.516	0.005	+	±	2E=30°-45°	a:a=26° ca.
Hastingsite. . . . .	Mono. . . .	1.516	Low	—	—		c:t=—25° to —30°.
Häuyite. . . . .	Isom. . . .	1.500					

## ALPHABETICAL LIST OF THE ROCK-FORMING MINERALS—Continued.

Name.	System.	Mean Index.	Maxim. Birefrin.	Optical Char.	Elong. Char.	2V or 2E.	Orientation.
Jedbergite.	Mono. . . .	1.740	0.019	+	.....	2V = 60°	c: t = -44°.
Jenatite.	Hex. . . .	3.08	0.28	-	+		
Jercynite.	Isom. . . .	1.749					a: a = Very small.
Jenlandite.	Mono. . . .	1.501	0.007	+	-	2V = 0°-50°	c: t = -12° to -20°.
Jornblende, common.	Mono. . . .	1.646	0.016	+	+	2V = 54°-84°	c: t = -0° to -12°.
Jornblende, basaltic.	Mono. . . .	1.719	0.072	-	+	2V = 80°	b = t, a = a.
Humite.	Ortho. . . .	1.643	0.035	+	.....	2V = 68°	a: a = -6°.
Hyalophane.	Mono. . . .	1.540	0.005	+	.....		c: t = 21°.
Hydrargillite.	Mono. . . .	1.542	0.023	+	-	2V = 0°-40°	c = b.
Hydromagnesite.	Ortho. . . .	1.567	Low	.....	±		
Hydronephelite.	Hex. . . .	1.49	0.012	+	+		
Hypersthene.	Ortho. . . .	1.670	0.013	-	+	2V = 70°-80°	b = a, c = t.
Idocrase. See Vesuvianite.							
Ilmenite.	Hex. . . .	High	High				
Iolite. See Cordierite.							
Jadeite.	Mono. . . .	1.654	0.029	+	.....	2V = 72°	c: t = -33.5°.
Kaolin.	Mono. . . .	1.54	0.008	-	+	Large	c: a = 13° ca.
Kataphorite.	Mono. . . .	.....	Low	+	.....	Small	c: t = -23° to -60°.
Labradorite.	Tricl. . . .	1.559	0.008	+	.....	2V = 75°-80°	*
Lamprophyllite.	Mono. . . .	1.697	0.035	.....	±		c: t = 20°.
Laumontite.	Mono. . . .	1.521	0.012	-	+	2E = 54°	c: a = 20°.
Lavenite.	Mono. . . .	1.750	0.040	-	+	2V = 80°	a = a, c = t.
Lawsonite.	Ortho. . . .	1.673	0.019	+	+	2V = 84°	c: a = -10°.
Lazulite.	Mono. . . .	1.625	0.036	-	.....	2E = 135°	c: a = 0° to 2°.
Lepidolite.	Mono. . . .	1.601	0.007	-	+	2E = 32°-84°	
Leucite.	Isom. . . .	1.508	0.001	-			
Magnesite.	Hex. . . .	1.649	0.202	-			
Magnetite.	Isom. . . .						

\* See p. 78.

## ALPHABETICAL LIST OF THE ROCK-FORMING MINERALS—Continued.

Name.	System.	Mean Index.	Maxim. Birefrin.	Optical Char.	Elong. Char.	2V or 2E.	Orientation.
Melanite.....	Isom.....	1.873	0.005	±	±	2V = 71°-84°	* c: t = 2° to 6°.
Mellite.....	Tetr.....	1.632				2E = 21°-36°	a = t, b = a.
Menacaumite. See Ilmenite.....						2V = 37.5°	c: a = 3°.
Microcline.....	Mono.....	1.523	0.007	—	—	2V = 70°	c: a = 0° to 2°.
Monazite.....	Ortho.....	1.811	0.045	—	—	2V = 30°-45°	a = a, c = t.
Monticellite.....	Mono.....	1.660	0.017	—	—	2V = 60°-62.5°	
Mosandrite.....	Mono.....	1.651	0.012	—	—	2E = 55°-90°	
Muscovite.....	Mono.....	1.587	0.038	—	—	2V = 96°	
Natrofite.....	Ortho.....	1.482	0.012	—	—		
Nephelite.....	Hex.....	1.540	0.005	—	—		
Noselite.....	Isom.....	1.495					
Octahedrite. See Anatase.....							
Oligoclase.....	Tricl.....	1.544	0.007	—	—	2V = 82°-90°	* a = t, b = a.
Oligoclase-albite.....	Tricl.....	1.538	0.009	—	—	2V = 84°-90°	c: a = 36° ca.
Olivine.....	Ortho.....	1.671	0.035	—	—	2V = 88°	a: a = 5° ca.
Orthite.....	Mono.....	1.682	0.032	—	—	Varying	c: t = 0° to 20°.
Orthoclase.....	Mono.....	1.522	0.006	±	±	2V = 70°-80°	c: a = 0° to 2°.
Ottrelite.....	Mono.....	1.741	0.010	—	—	Large	c: t = 18° to 21°.
Paragonite.....	Mono.....	1.587	0.038	—	—	2E = 70°	c: a = -5°
Parasite.....	Mono.....	1.623	0.020	—	—	2V = 52°-60°	c: t or a = 0°
Pectolite.....	Mono.....	1.61	0.038	—	—	2V = 60°	
Pennine. (Chlorite).....	Mono.....	1.582	0.002	±	±	2E = 0° to 61°	
Peridot. See Olivine.....							
Perovskite.....	Isom.....	2.38					
Phillipsite.....	Mono.....	1.54	0.003	—	—	Large	a: t = 11° to 18°.
Plagioclase.....	Mono.....	1.591	0.044	—	—	2E = 0°-35°	c: a = 0° to 7°.
Piedmontite.....	Mono.....	1.734	0.032	±	±	2V = 90°	c: a = 5° to 6°.
Pistachite (Epidote).....	Mono.....	1.734	0.032	—	—	2V = 74°-90°	c: a = 3°.

\* See p. 78.

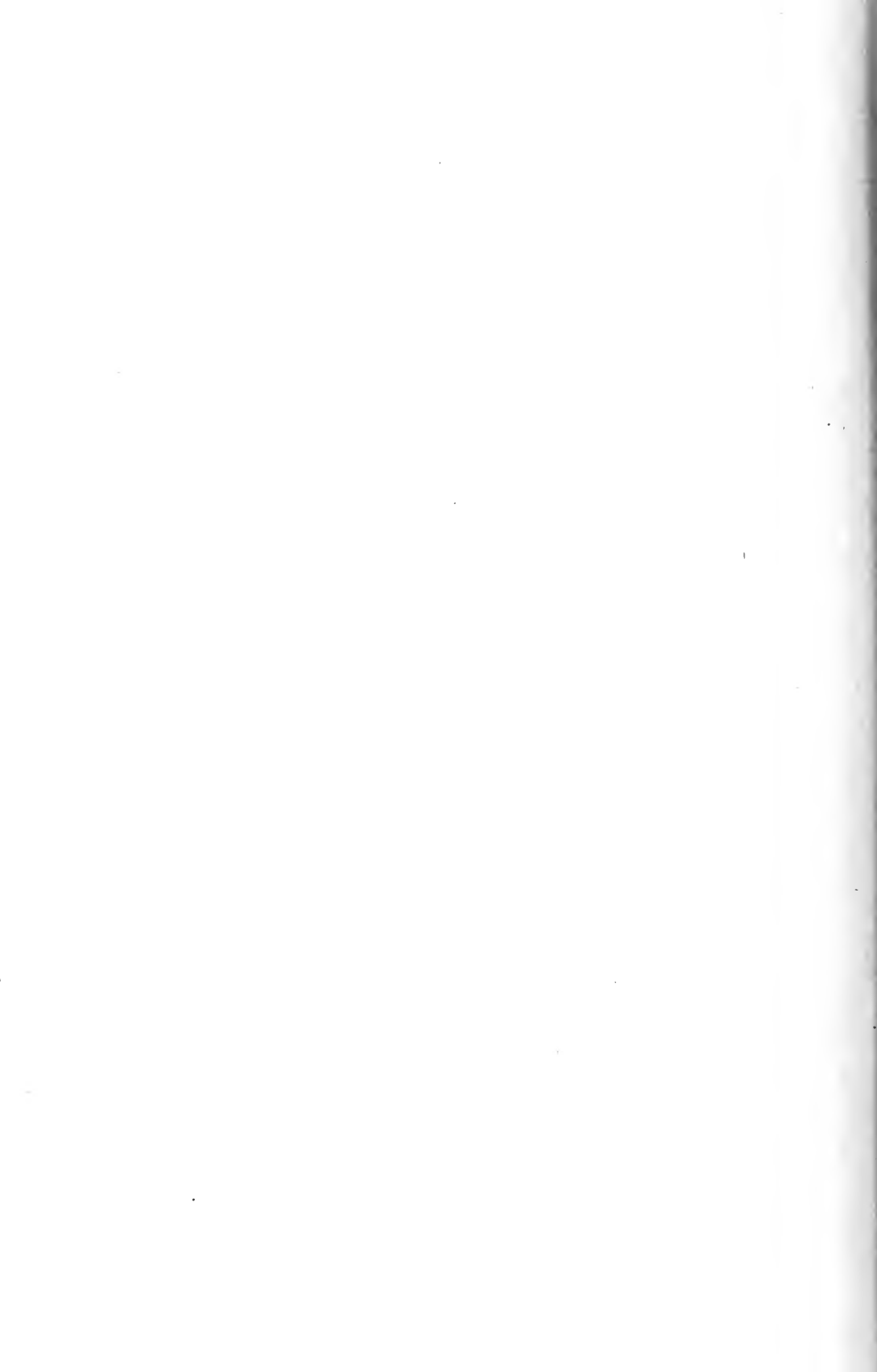
## ALPHABETICAL LIST OF THE ROCK-FORMING MINERALS—Continued.

Name.	System.	Mean Index.	Maxim. Birefrim.	Optical Char.	Elong. Char.	2V or 2E.	Orientation.
Pleonaste, . . . . .	Isom. . . . .						
Prehnite, . . . . .	Ortho. . . . .	1.630	0.033	+	—	2V=69°	a = a, c = f.
Pseudobrookite, . . . . .	Ortho. . . . .	High	High	+	±	2H=84.5°	a = f, b = a.
Pyrite, . . . . .	Isom. . . . .						
Pyrope, . . . . .	Isom. . . . .	1.745					
Pyrrhotite, . . . . .	Hex. . . . .						
Quartz, . . . . .	Hex. . . . .	1.550	0.009	+	—	2E=anom. 18° and less	c: f = -85°.
Riebeckite, . . . . .	Mono. . . . .	1.687	0.004	+	+	2E=78°-82.5°	c: b = 7° ca.
Rinkite, . . . . .	Mono. . . . .	1.668	0.003	+	+	2V=90° nearly	c: f = 13°.
Rosenbuschite, . . . . .	Mono. . . . .	1.65	0.026	—	—		c = f.
Rutile, . . . . .	Tetr. . . . .	2.711	0.287	+	+	2E=32°-36°	c: f = -44° ca.
Salite, . . . . .	Mono. . . . .	1.683	0.029	+	—	2V=29°	*
Sandine, . . . . .	Mono. . . . .	1.522	0.006	—	—	2V=69°	c: f = 8° to 9°.
Sapphirine, . . . . .	Mono. . . . .	1.709	0.005	—	+	2E=50°-60°	c: a = 17°.
Scodécite, . . . . .	Mono. . . . .	1.502	0.007	—	+	2E=16°-50°	b = a, c = f.
Serpentine, . . . . .	Ortho. . . . .	1.54	0.013	—	—		
Siderite, . . . . .	Hex. . . . .	1.796	0.238	+	+	2V=20°-33°, 2E=34°-58°	b = a, c = f.
Sillimanite, . . . . .	Ortho. . . . .	1.667	0.022	+	+		
Sodalite, . . . . .	Isom. . . . .	1.483					
Spessartite, . . . . .	Isom. . . . .	1.811					
Spinel. See Titanite.							
Spodumene, . . . . .	Isom. . . . .	1.718					
Staurolite, . . . . .	Mono. . . . .	1.667	0.016	+	—	2V=54°-60°	c: f = -23° to -26°.
Stibnite, . . . . .	Ortho. . . . .	1.741	0.010	+	+	2V=80°	b = a, c = f.
Talc, . . . . .	Mono. . . . .	1.497	0.006	—	—	2E=52°	c: a = 8° ca.
Thomsonite, . . . . .	Ortho. . . . .	1.572	0.050	—	—	2V=0°-17°	b = f, c = a.
Thulite, . . . . .	Ortho. . . . .	1.508	0.028	+	+	2E=87°	a = a, b = f.
		1.702	0.009	+	±	2V=0°-40°	a = f, c = a.

\* See p. 68.

## ALPHABETICAL LIST OF THE ROCK-FORMING MINERALS—Continued.

Name.	System.	Mean Index.	Maxim. Birefrim.	Optical Char.	Elong. Char.	2V or 2E.	Orientation.
Titanaugite. ....	Mono. ....	.....	High	+	.....	Less than 60°	$c:r = -45^\circ$ to $-55^\circ$ .
Titanite. ....	Mono. ....	1.938	0.145	+	.....	$2E = 45^\circ-68^\circ$	$c:r = 39^\circ$ .
Titanolivine. ....	Mono. ....	1.683	0.033	+	.....	$2V = 58^\circ$	$b = c$ .
Topaz. ....	Ortho. ....	1.623	0.009	+	.....	$2V = 50^\circ-67^\circ$ , $2E = 71^\circ$	$a = a$ , $c = c$ .
Tourmaline. ....	Hex. ....	1.650	0.017	—	—		
Tremolite. ....	Mono. ....	1.617	0.026	—	+	$2V = 87.5^\circ$	$c:r = -16^\circ$ .
Tridymite. ....	Hex. ....	1.477	0.002	+	—		
Triphane. See Spodumene. ....							
Uwarowite. ....	Isom. ....	1.838					
Vesuvianite. ....	Tetr. ....	1.723	0.006	±	±		
Wollastonite. ....	Mono. ....	1.714	0.026	+	.....	$2V = 72^\circ-77^\circ$	$c:r = 44^\circ$ .
Wöhlerite. ....	Mono. ....	1.581	0.040	—	+	$2E = 10^\circ-60^\circ$	$c:a = 0^\circ$ to $7^\circ$ .
Zinnwaldite. ....	Mono. ....	1.628	0.015	—	±	$2V = 40^\circ$ , $2E = 70^\circ$	$c:a = 32^\circ$ .
Zircon. ....	Tetr. ....	1.952	0.05	+	+		
Zoisite. ....	Ortho. ....	1.702	0.009	+	±	$2V = 0^\circ-60^\circ$	$a = c$ , $c$ or $b = a$ .





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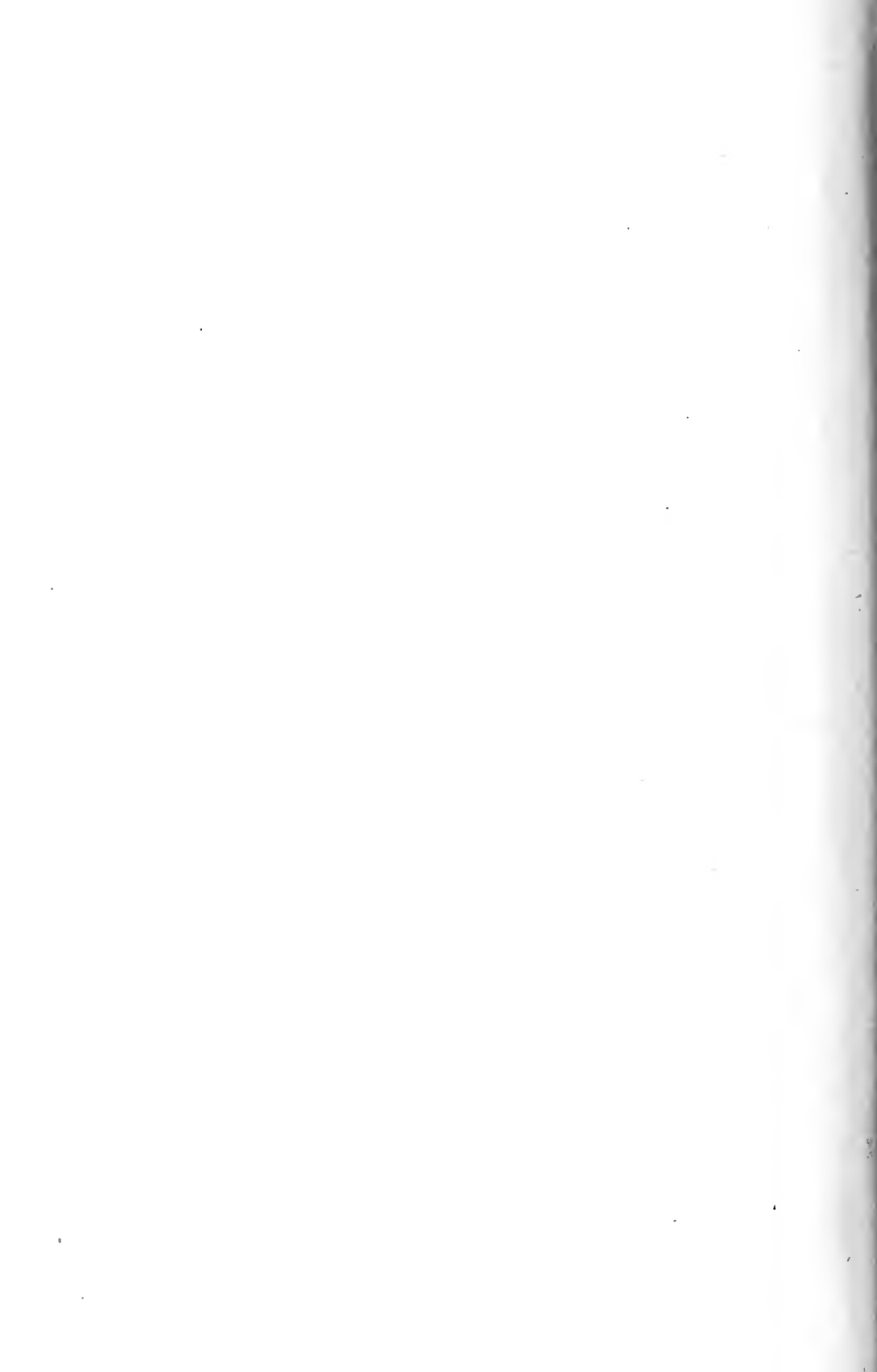
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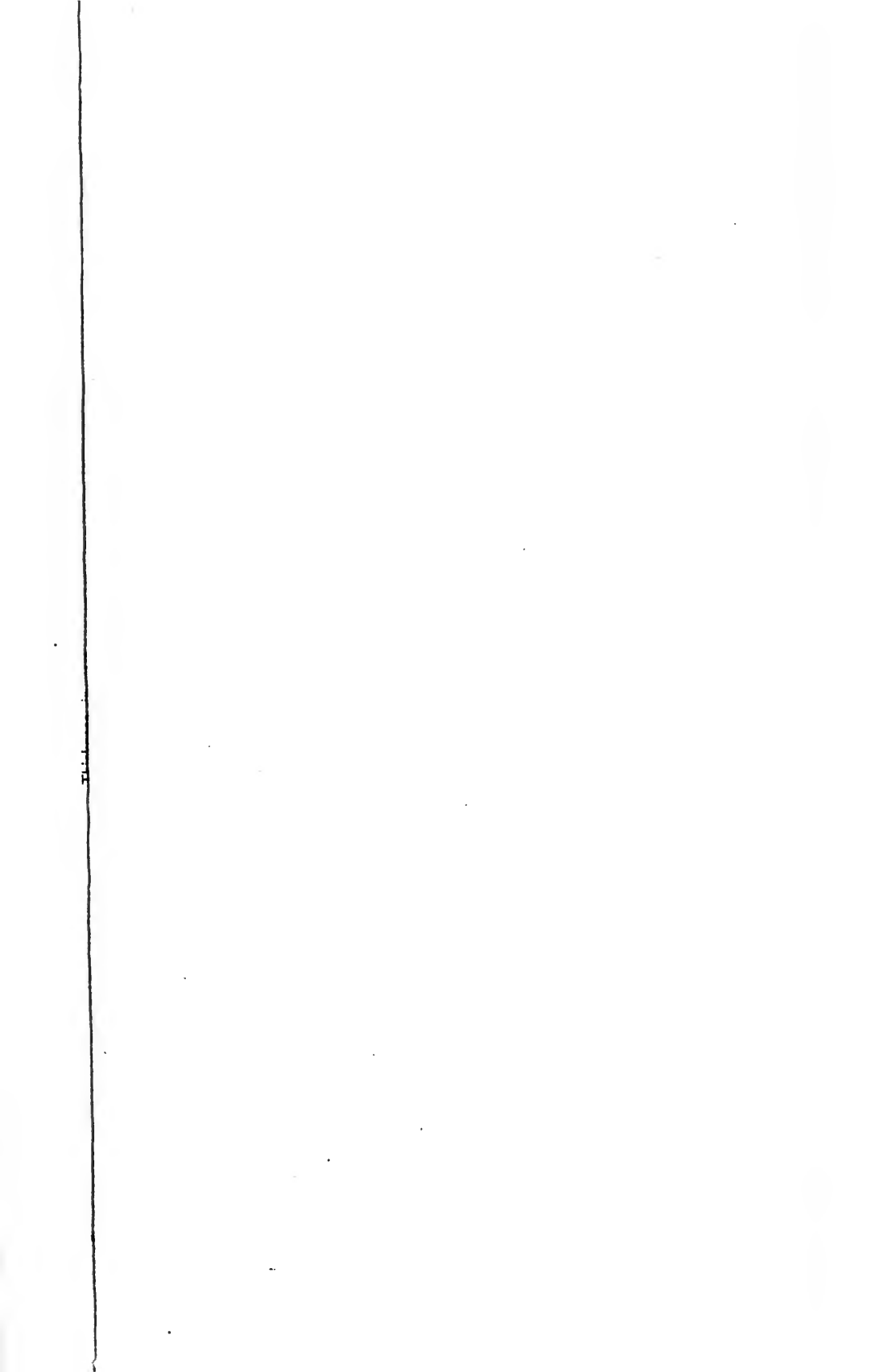
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(The manuscript of the tables of Part III was completed early in 1905; the final copy of the complete book, March 1, 1906; and the lettering of the diagrams, February 28, 1907.)





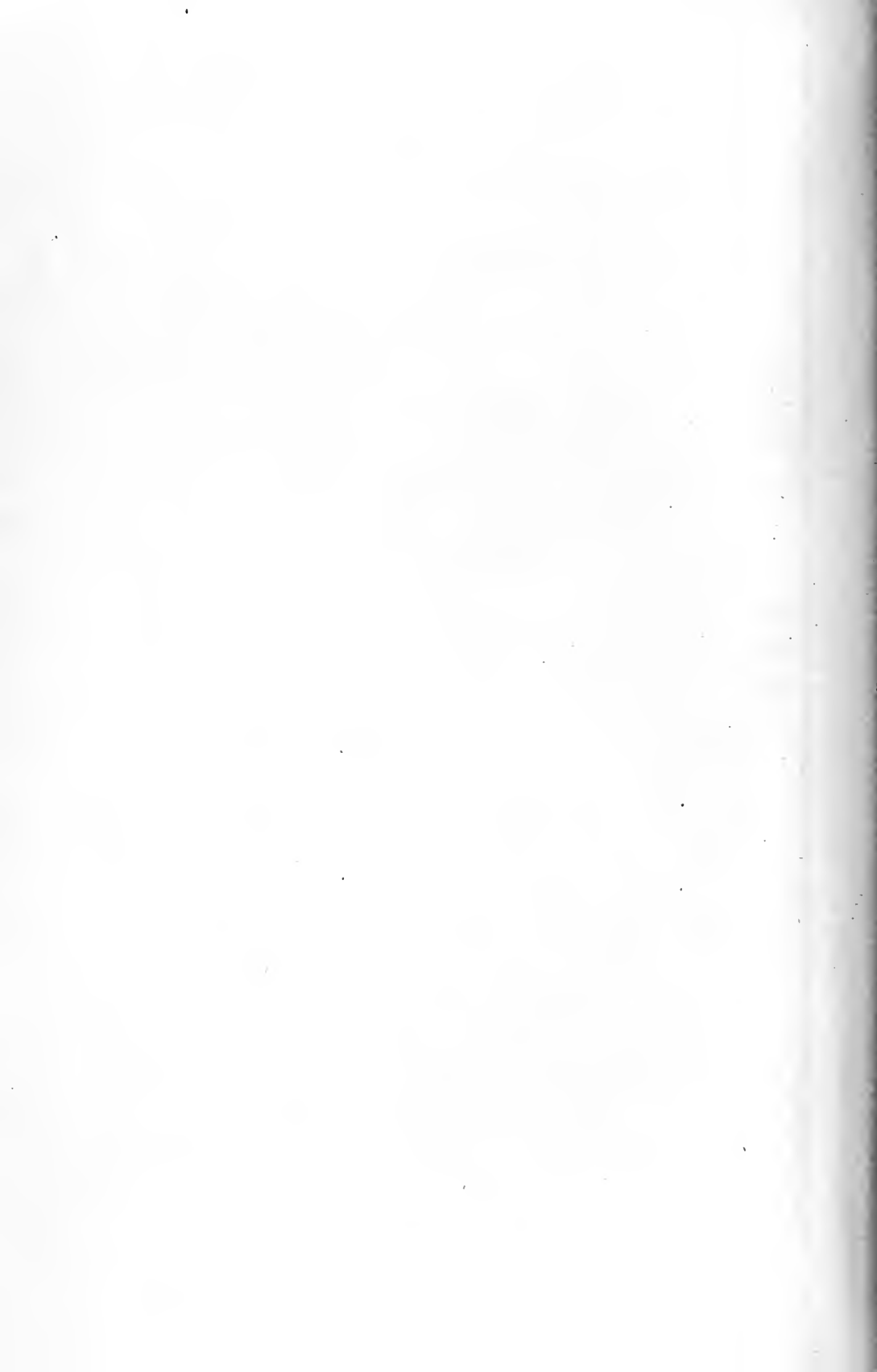




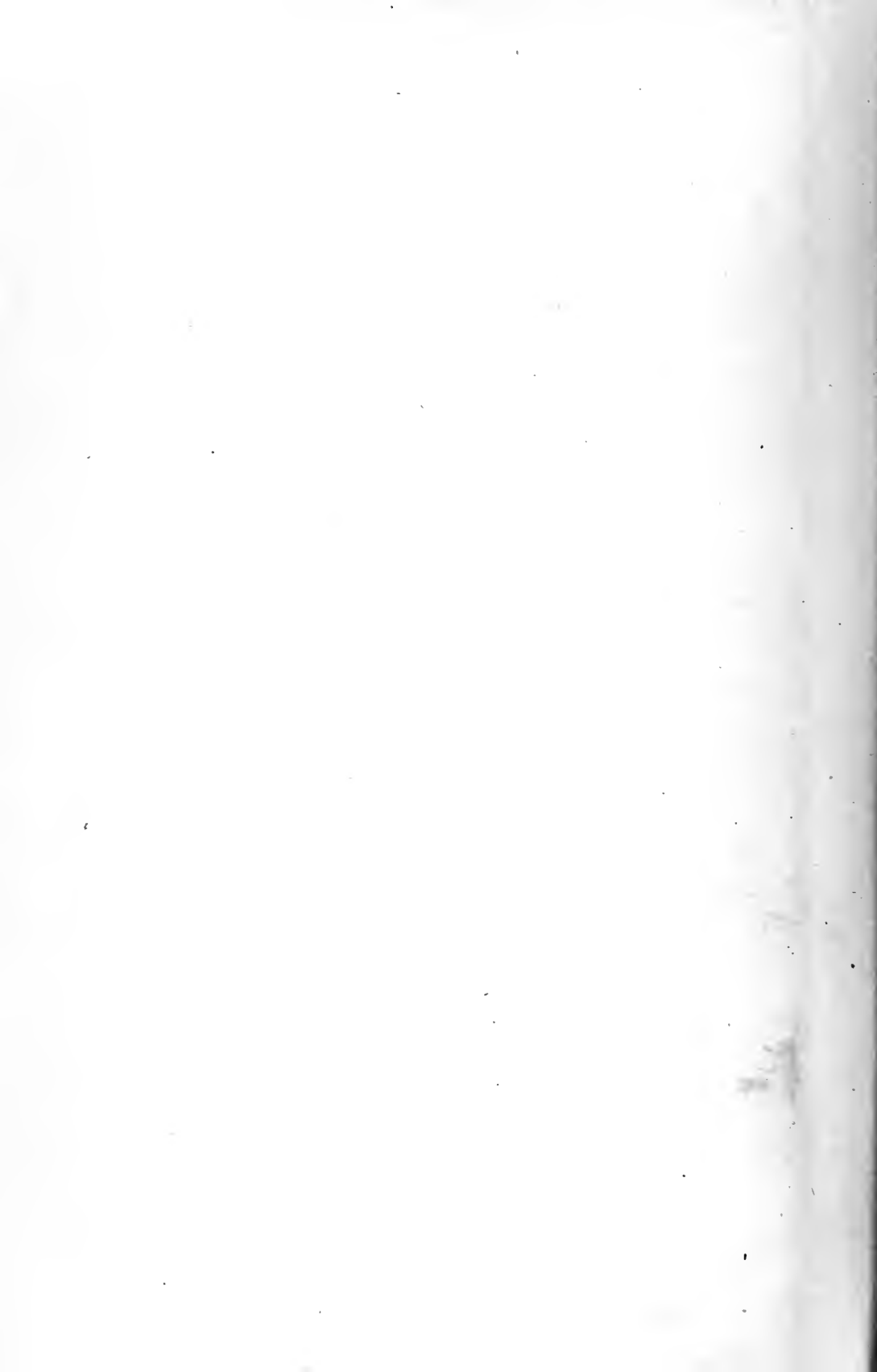
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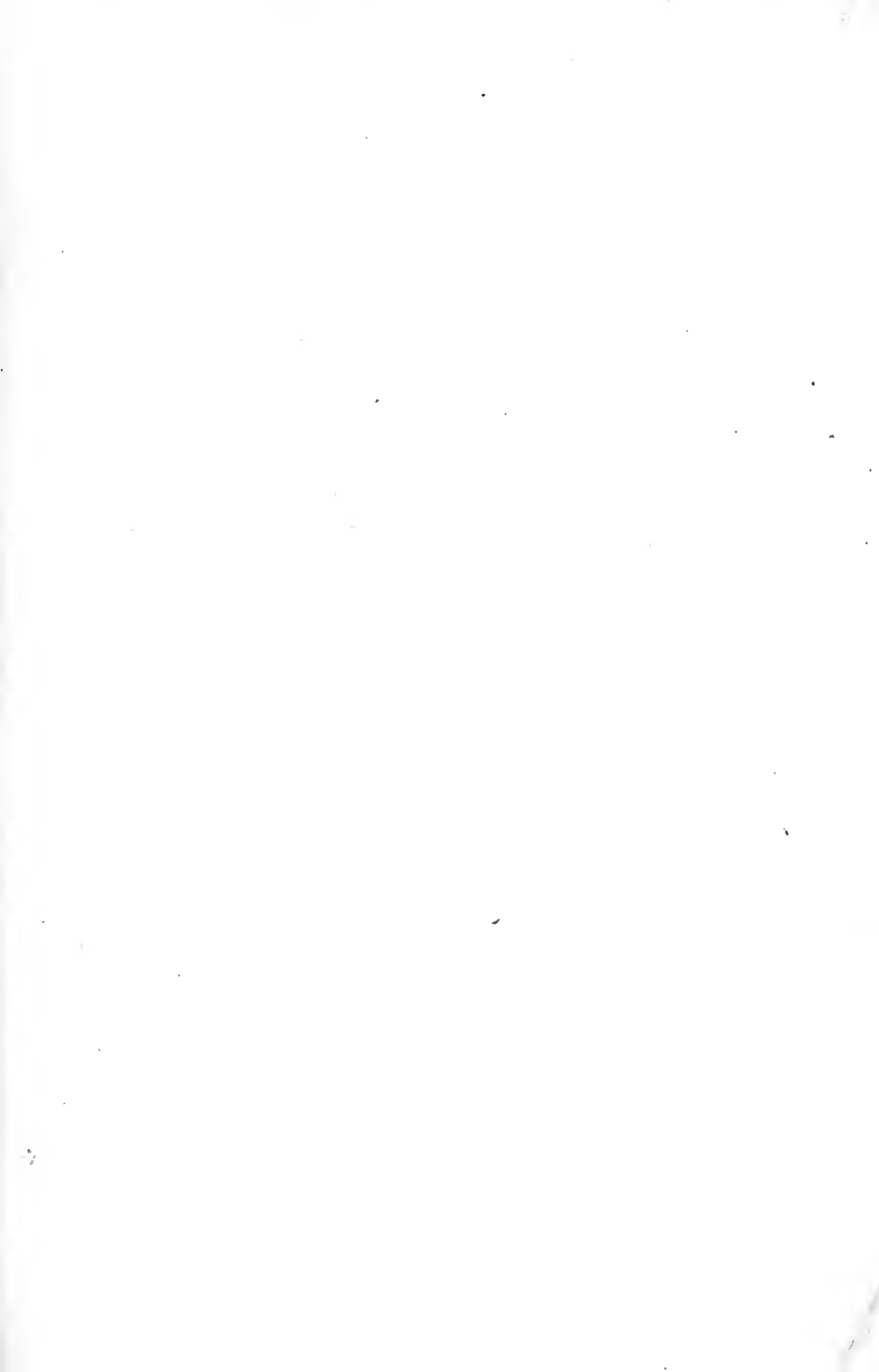














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